First CDF Run II Results

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DESY
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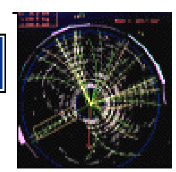
Fermi National Accelerator Laboratory
inquiring minds

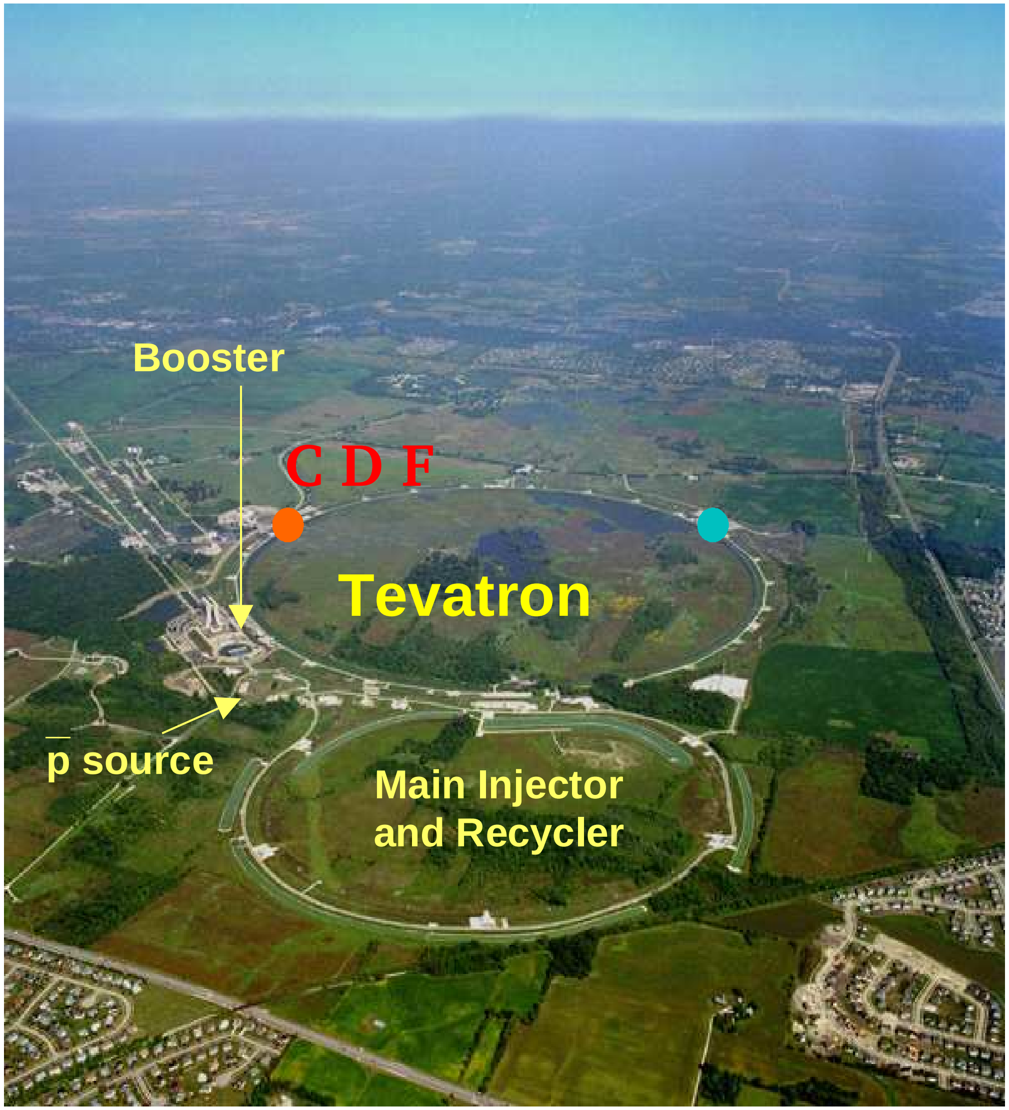


Outline

- The Fermilab accelerator complex
- The CDF II detector
  - Tracking, particle ID
  - Data acquisition and trigger
  - Operations and status
- Goals for Run II (a and b)
- First results
  - Heavy Flavors: lifetimes, masses, branching ratios
  - A few appetizers from other areas
- Summary

Fermilab Accelerator Complex

- Fermilab Tevatron
  - R = 1km, E_{beam} = 1TeV, B = 4.5T
  - $N \cdot 10^{11}$ ($N \cdot 10^{10}$) p (pbar) per bunch
  - 36 colliding p and pbar bunches
- Goal
  - A high beam-beam crossing rate but with <N> $\simeq$ 1 collisions per crossing (expect 1-10)



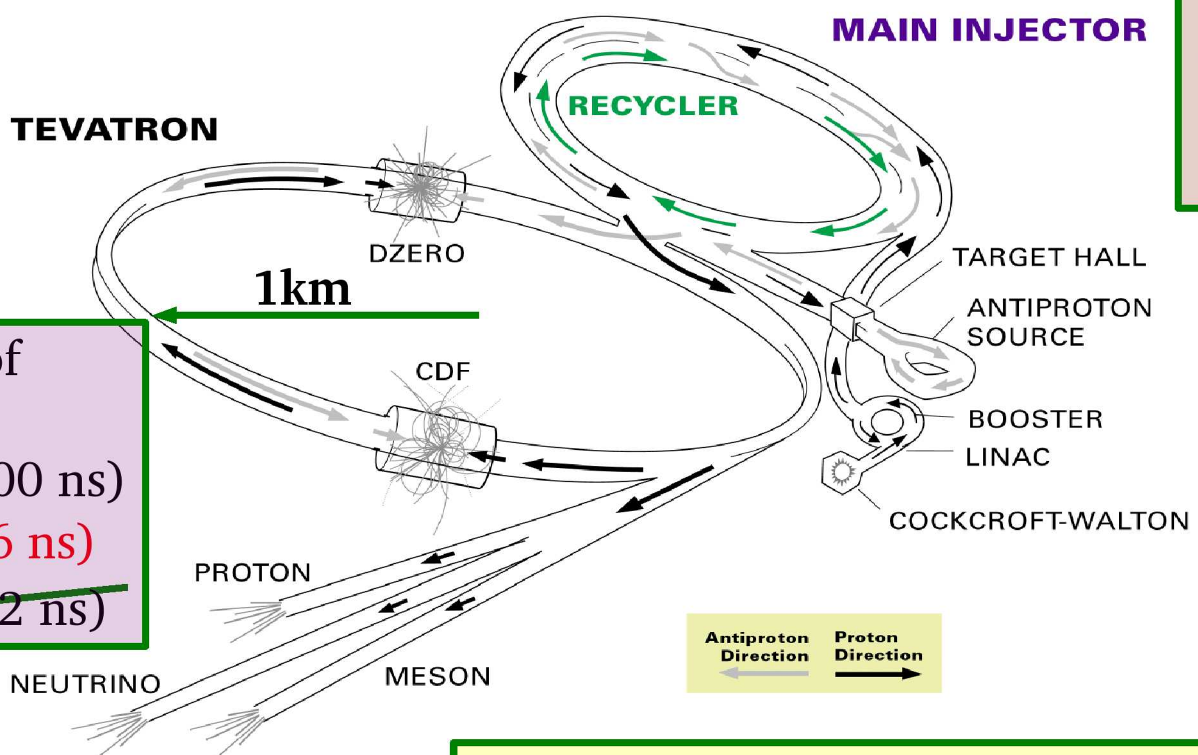
Accelerator Upgrades

$p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV
(up from 1.8TeV)

Main Injector
(p storage ring up to 150GeV)
replaces Main Ring: x5

Recycler storage ring for antiprotons: factor 2-3 in luminosity (2003-4)

FERMILAB'S ACCELERATOR CHAIN



Increased # of bunches:
6 (3500 ns)
→ 36 (396 ns)
→ ~~~100 (132 ns)~~

New stochastic cooling system for antiprotons

2005++: electron cooling, crossing angle, electron lens, luminosity levelling, ...: factor 2-3

Accelerator Upgrades cont.

- More protons
- More antiprotons
- Higher $\bar{p}$ production rate
- Smaller bunch spacing

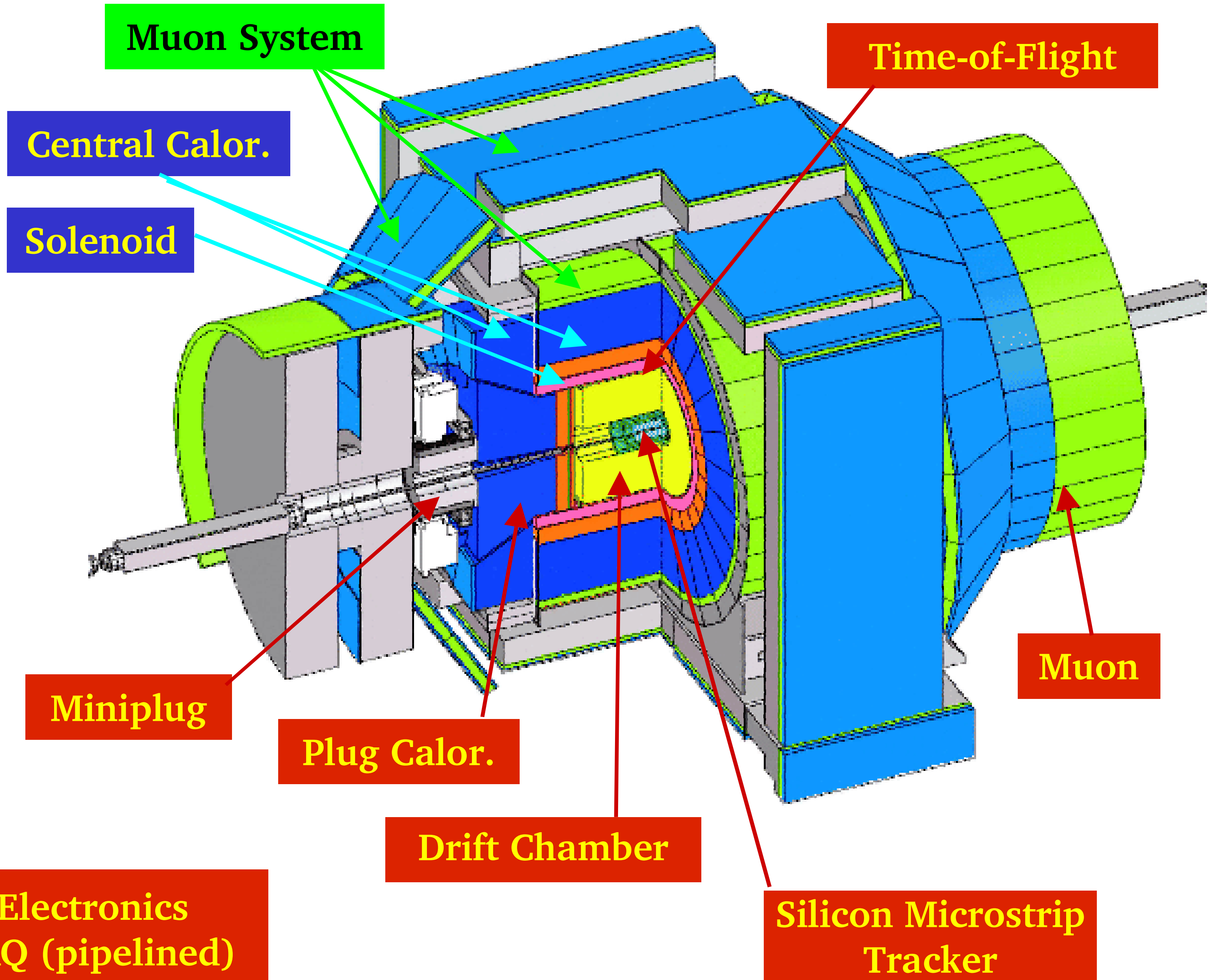
$\Rightarrow$ **Higher luminosity Comparable number of interactions per crossing**

- Initial peak luminosity $1.6 \cdot 10^{31} cm^{-2}s^{-1}$ (Run I)
  - $\rightarrow$ $8 \cdot 10^{31} cm^{-2}s^{-1}$ (Run IIa, 2003)
  - $\rightarrow$ $2 \cdot 10^{32} cm^{-2}s^{-1}$ (Run IIa + Recycler)
  - $\rightarrow$ up to $4 \cdot 10^{32} cm^{-2}s^{-1}$ (Run IIb)
- Run IIa: $\int L\,dt \simeq 2\ fb^{-1}$ by the end of 2004 (factor 20 compared to Run I)
  - 8 months shutdown in 2005 (Radiation damage to Silicon detectors, will not survive more than $\sim 5\ fb^{-1}$)
- Run IIb (2006 - "LHC physics") $\rightarrow \int L\,dt \simeq 10 - 15\ fb^{-1}$
- Typically factor up to 200 in statistics from accelerator upgrades alone
  - Add detector upgrades, improved acceptance, or completely new capabilities

New

Old

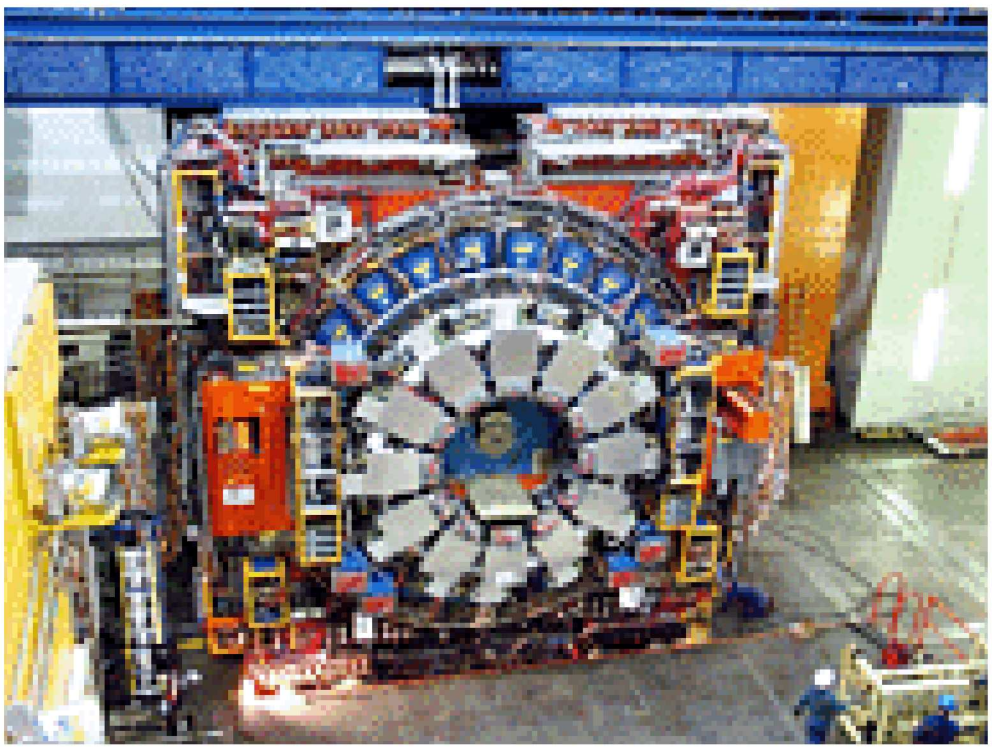
Partially New



Front End Electronics
Triggers / DAQ (pipelined)
Online & Offline Software

Experiment Status

- Run II started in April 2001 – stable physics running established early 2002
  - All major components commissioned by February 2002, using $\sim 20\ pb^{-1}$ of data
  - Still partially in commissioning are parts of Level 2 trigger and Silicon
- Up to $\int L\,dt \simeq 20\ pb^{-1}$ of “physics quality data” used in analyses
  - Expect about 100 pb^{-1} for “winter” conferences
- **Shown here are the first Run II physics results**

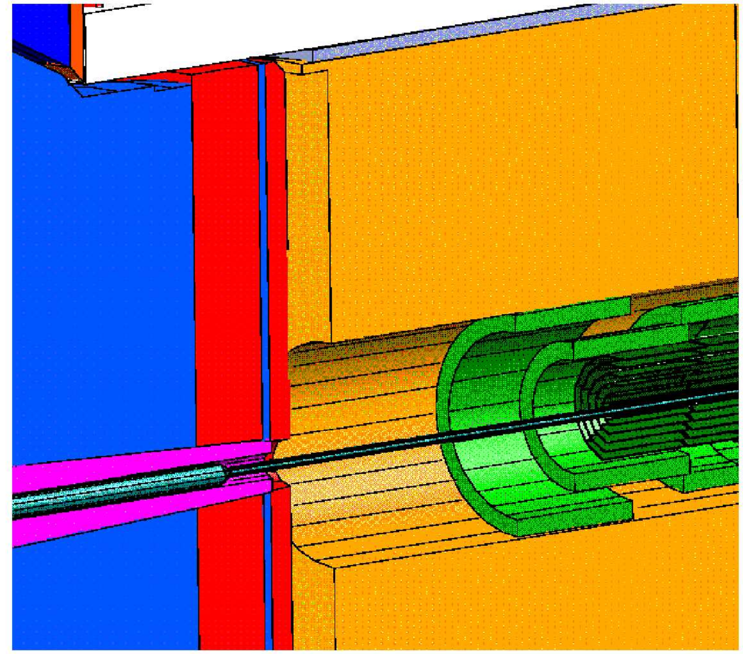


Detector roll-in February 2001

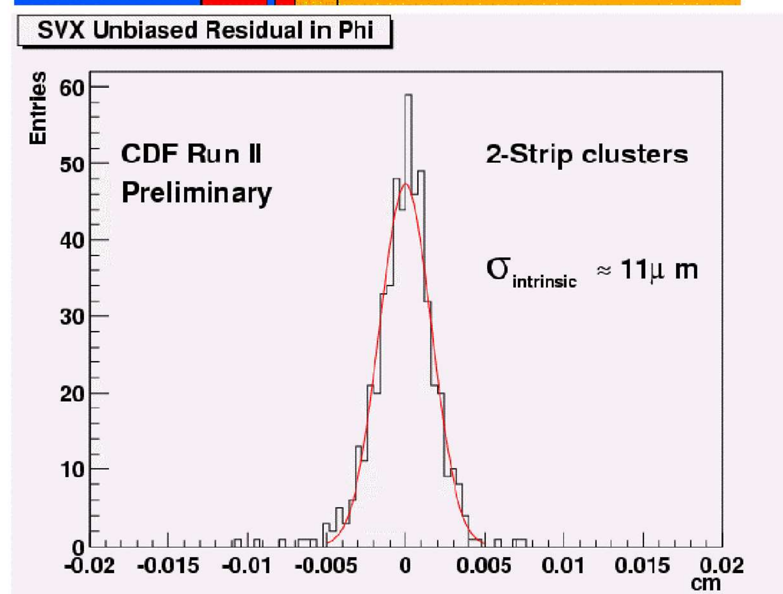
Tracking System: Silicon Detectors

- 3 parts: L00, SVXII (feeds Silicon Vertex Trigger), ISL
- Double sided microstrips detector (L00 single-sided)
- SVX II: S/N $\simeq$ 12, hit efficiency > 99%
- Impact parameter resolution: $\sigma_\phi < 30\ \mu$m, $\sigma_z < 60\ \mu$m
- $|\eta| < 2$, $|z| < 45$cm
- Overall twice the acceptance of the Run I Silicon

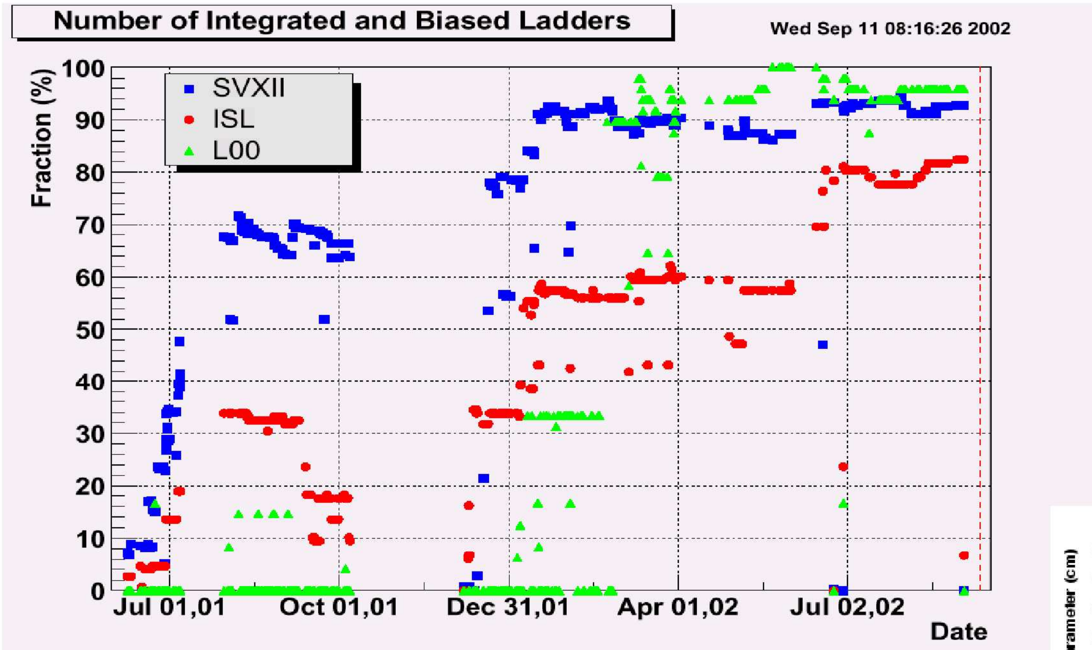
2b's or not 2 b's?
Double tags essential for M_{top}, H $\rightarrow$ bb



CDF	Layer 00	SVX II	ISL	Totals
Layers	1	5	2	8
Length	0.9 m	0.9 m	1.9 m	
Channels	13824	405504	303104	722432
Modules	48 SS	360 DS	296 DS	704
Readout Length	14.8 cm	14.5 cm	21.5 cm	
Inner Radius	1.35 cm	2.5 cm	20 cm	1.35 cm
Outer Radius	1.65 cm	10.6 cm	28 cm	28 cm
Power	~100 W	1.4 kW	1.0 kW	2.5 kW

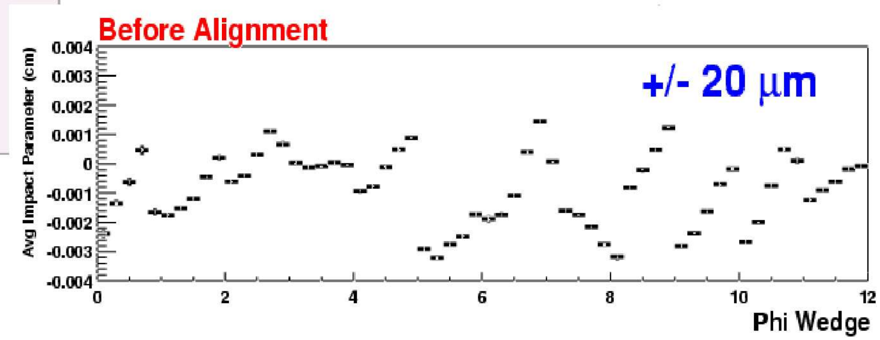


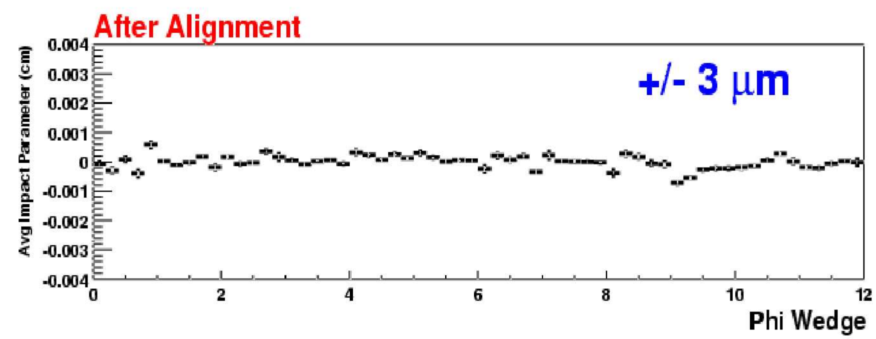
Silicon Detectors Status



Percent of Silicon ladders that are read out:

L00 > 95%
SVXII > 90%
ISL > 80%



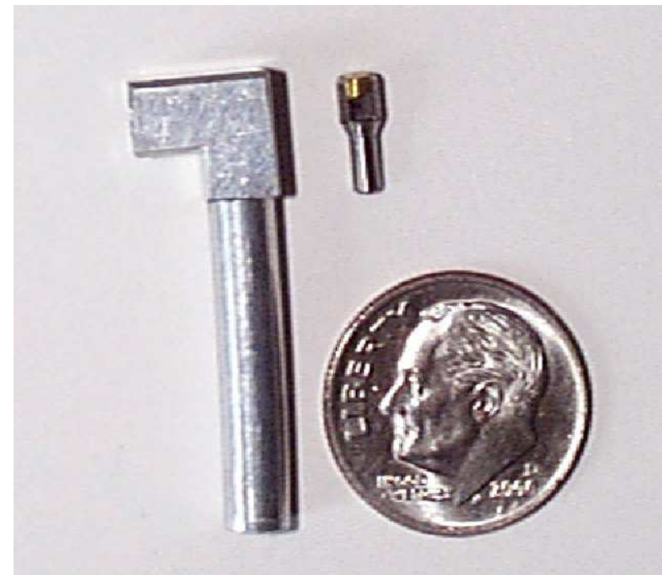


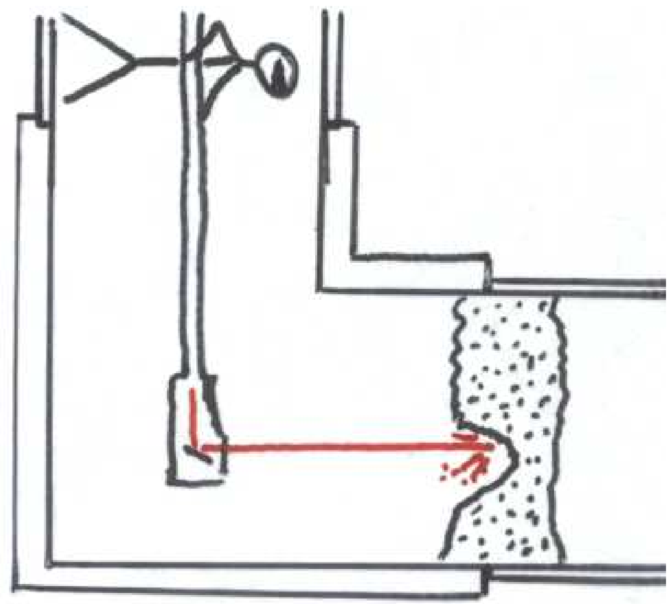
Alignment in r-ϕ is well advanced

Note: none of the results shown later include L00, stereo information from SVXII, or central ISL.
But all of the above are now ready for physics analysis.

ISL Cooling (Angioplasty)

High power laser and custom prisms to clear lines from Epoxy





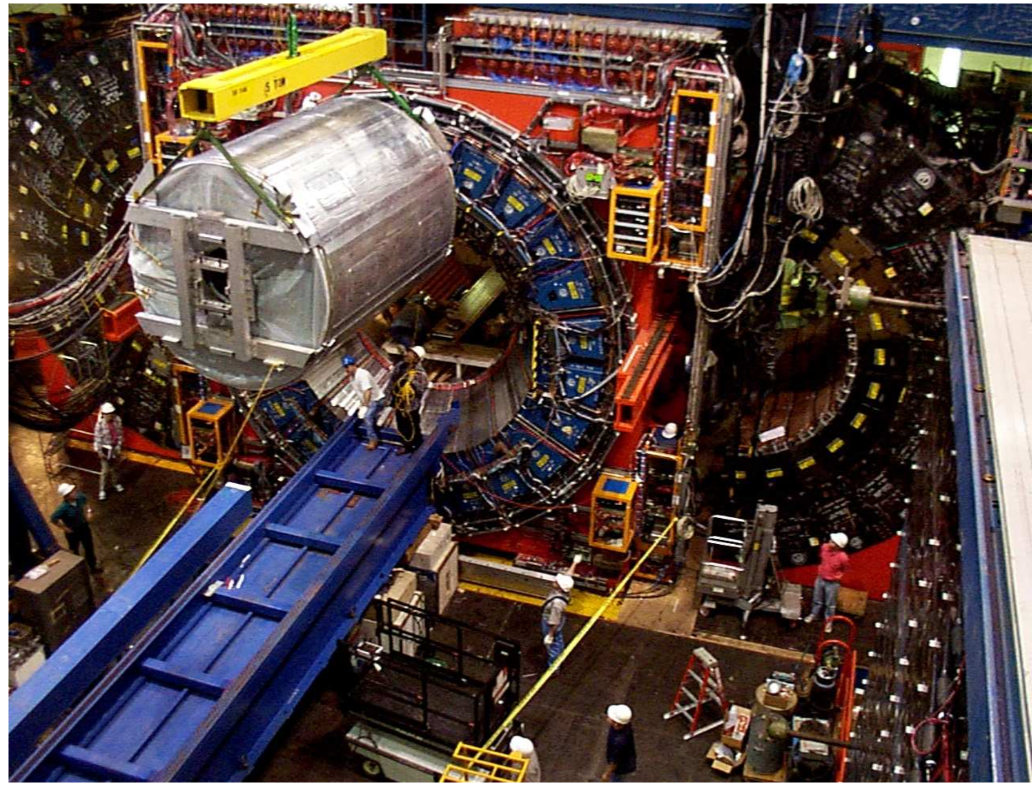
Status:

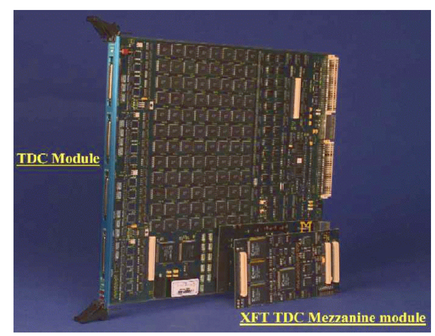
All but 3 lines cleared during June shutdown!

Remaining lines will be done during next extended shutdown

Central Outer Tracker

- New Detector & Electronics
  - **Smaller cell size** (4x # of cells), max drift distance $\simeq$ 1cm
  - **100ns maximum drift time** with fast gas (Ar-Et-CF_4 50:35:15)
  - **8 superlayers x 12 wires** = 96 space points; 30240 sense wires
  - 50% are 3° stereo (better stereo capability, 24 $\rightarrow$ 48 points)
  - 315 multi-hit TDC boards in 20 crates, 1ns resolution



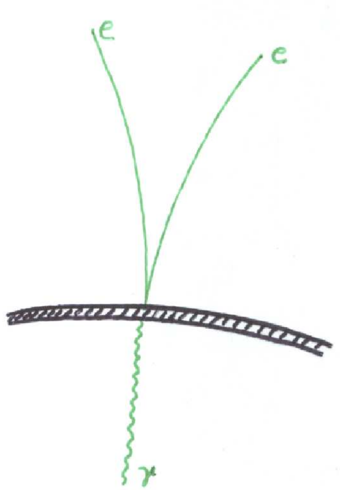


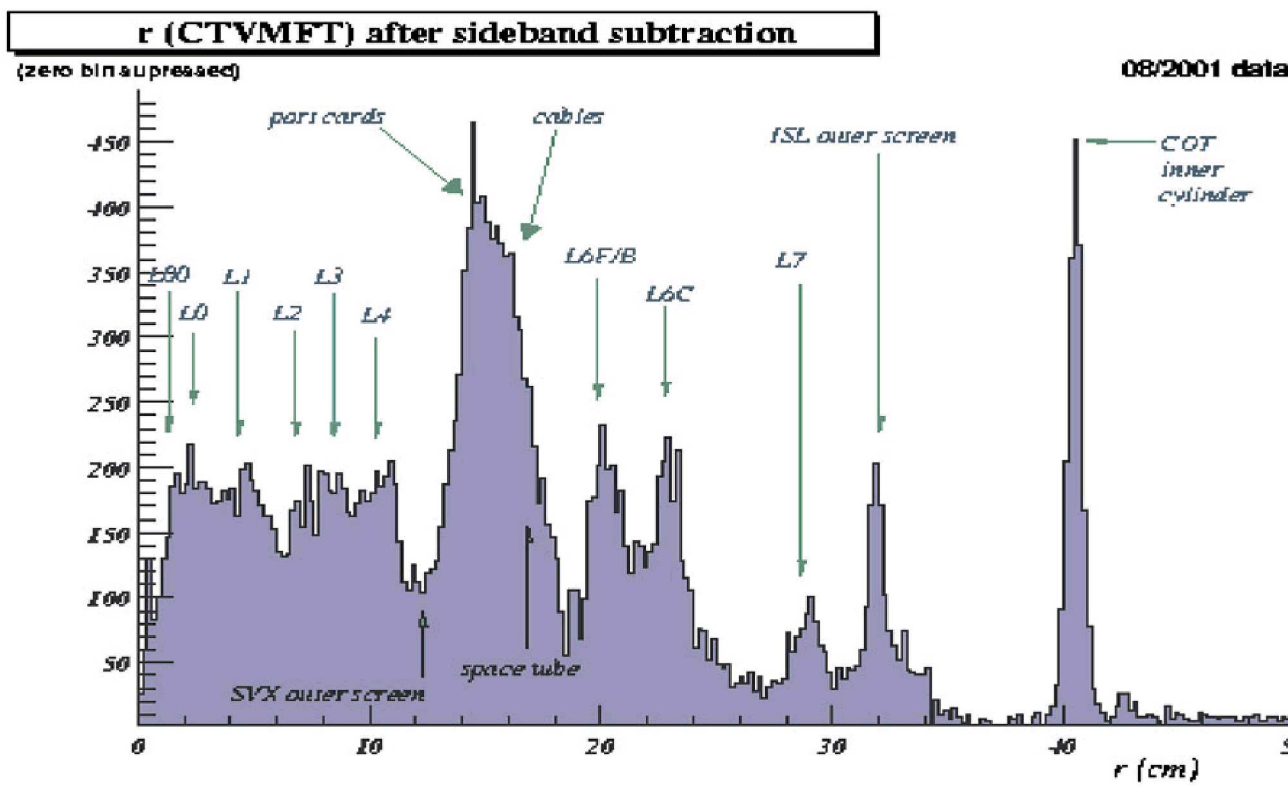
- 40cm < r < 140cm, $|\eta| < 1$, hit resolution $\simeq$ 175μm
- **Measured single track efficiency 100% for high p_T isolated tracks**

Central Outer Tracker cont.

- Low mass: 1.4% X_0 in the active volume at $\Theta = 90^\circ$

Detector X-ray using conversions



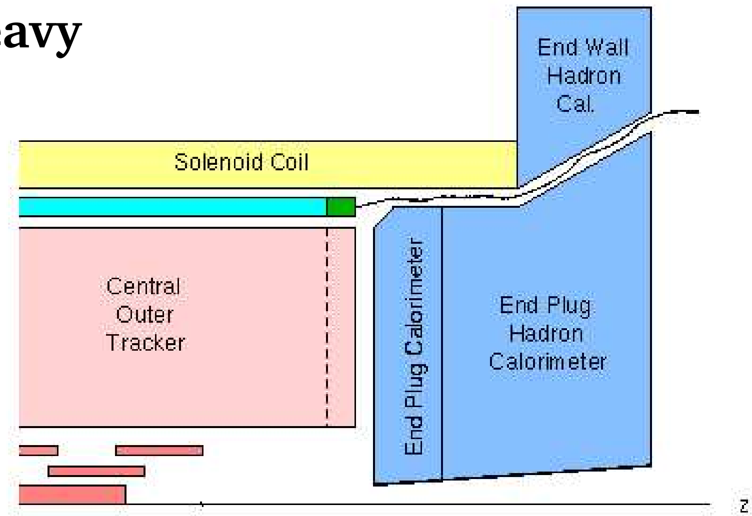


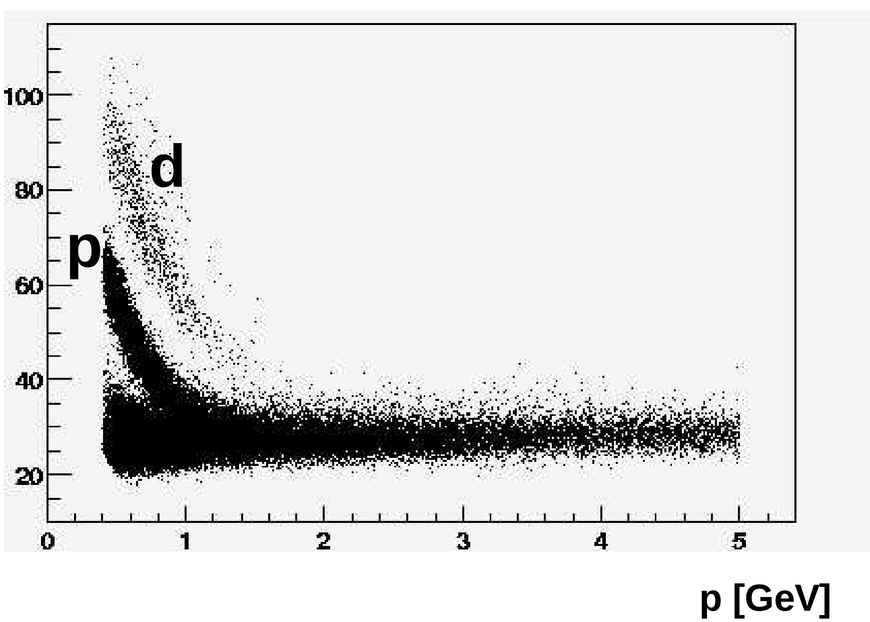
PID: Time-of-Flight and dE/dx

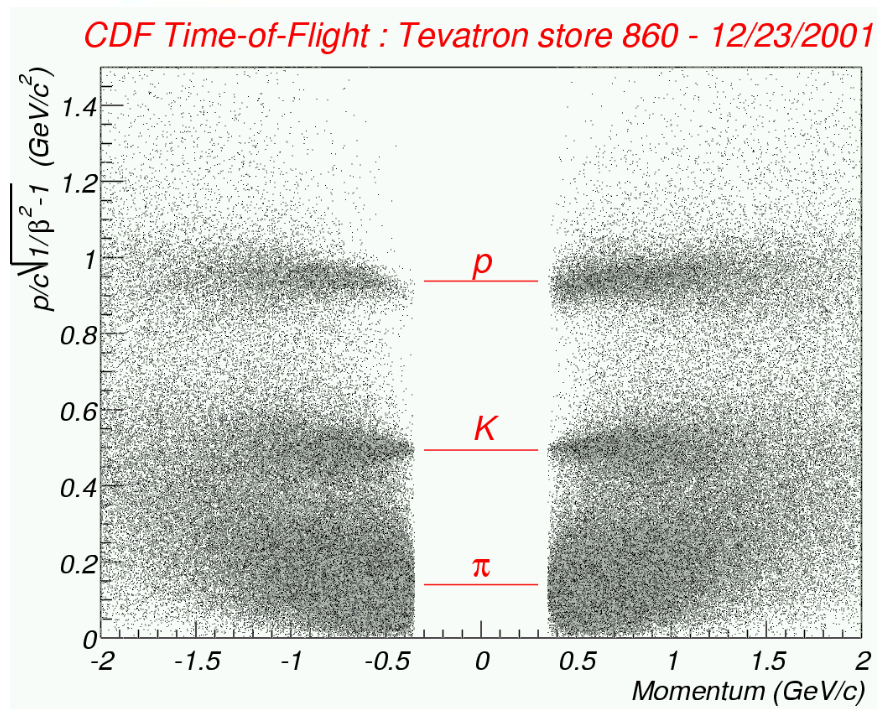
Particle ID is a typical weak point of doing heavy quark physics at a hadron collider!

TOF scintillator bars
216 x 2 PMT channels at R=1.4m
100ps timing resolution (125ps achieved)

COT wires
96 pulse height measurements
dE/dx measured from pulse width
via ASD + TDC electronics

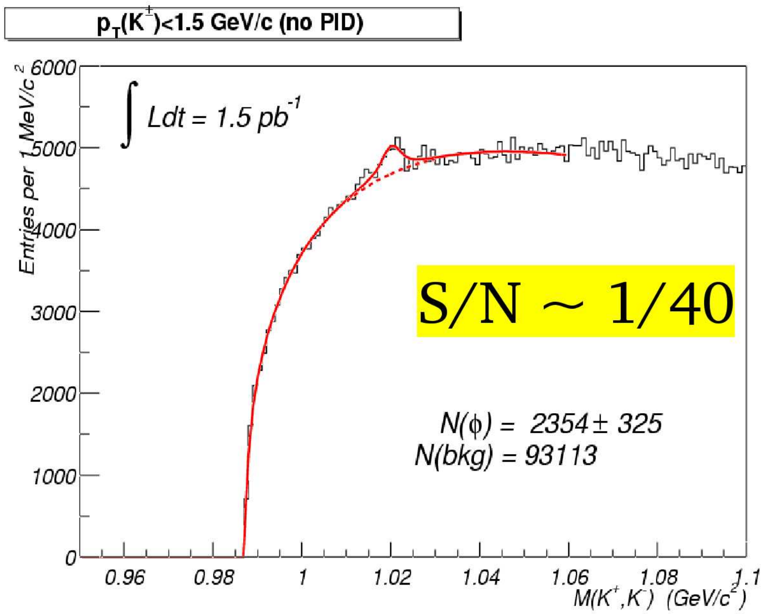


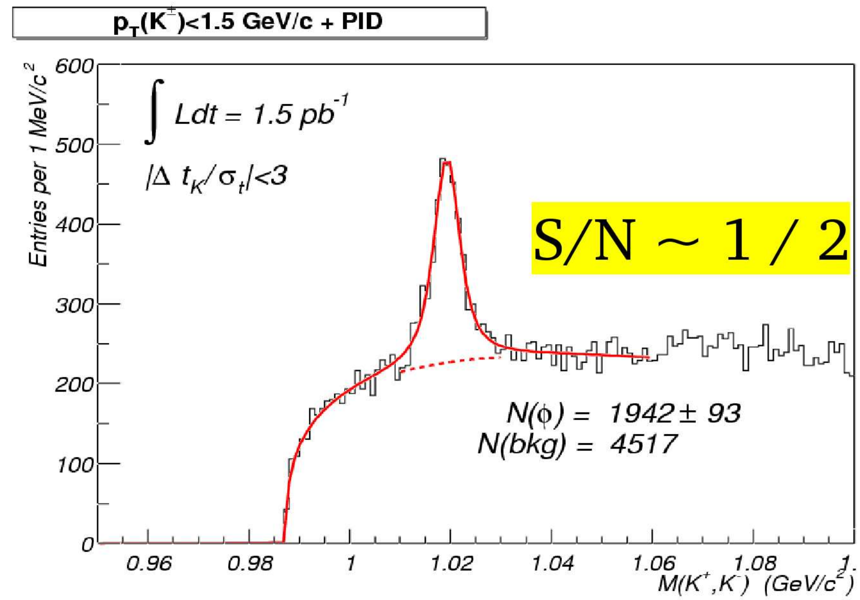


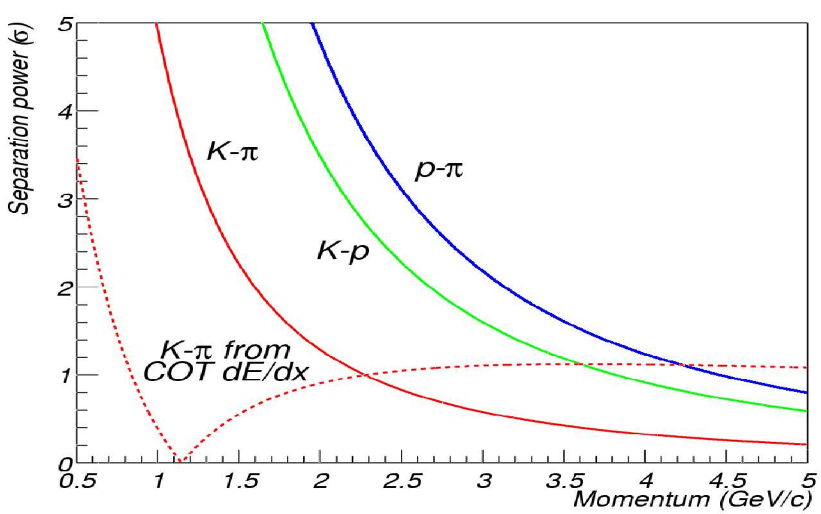


Time-of-Flight cont.

Tag low pt Kaons in $\phi \to$ KK





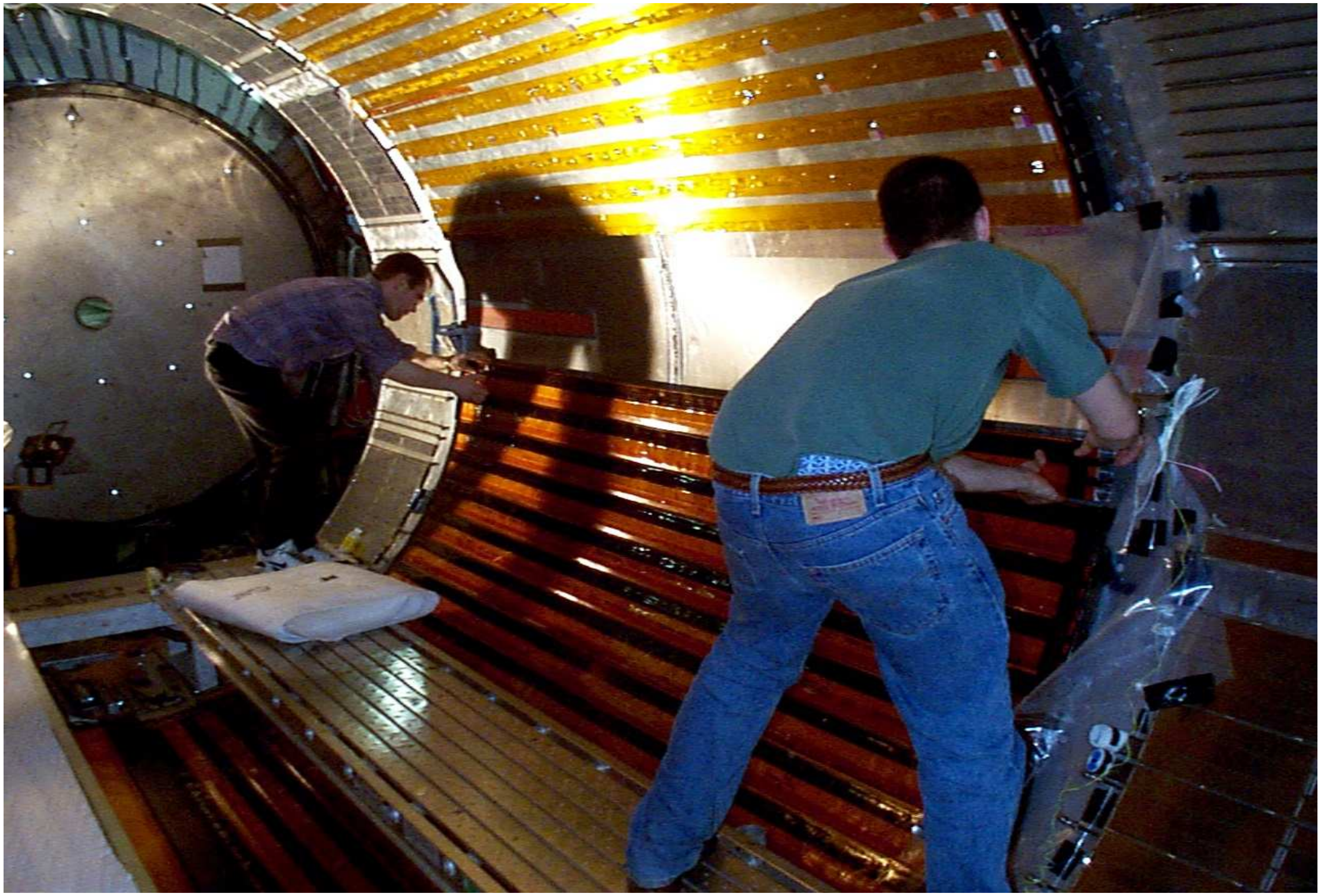


2σ separation of

- K and π for p < 1.6 GeV
- p and K for p < 2.7 GeV
- p and π for p < 3.2 GeV

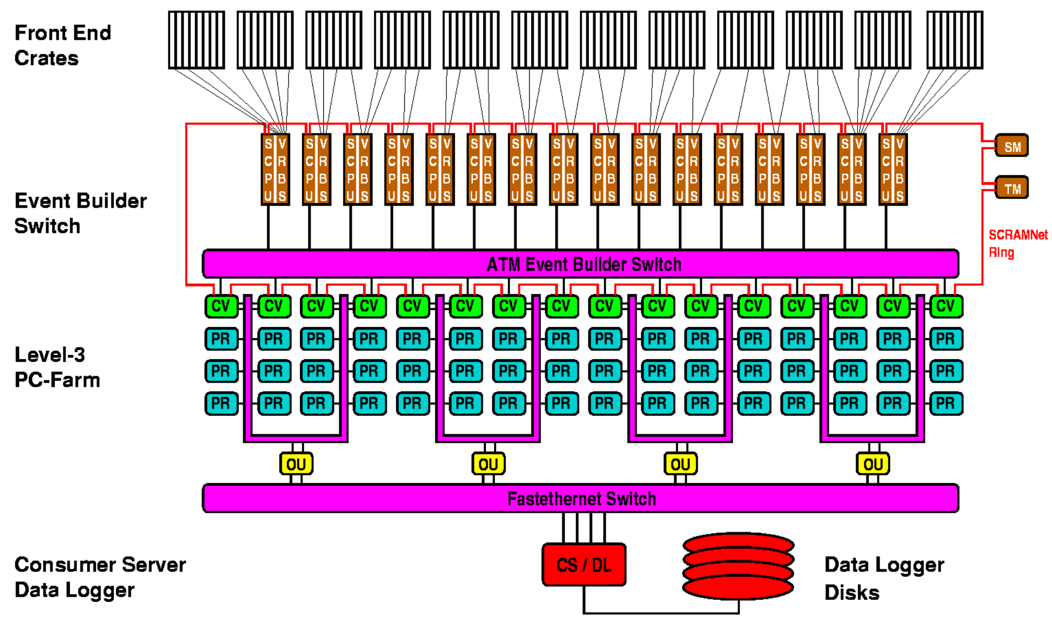
Time-of-Flight Installation

Exploiting every mm of space ...



DAQ, Trigger, Electronics

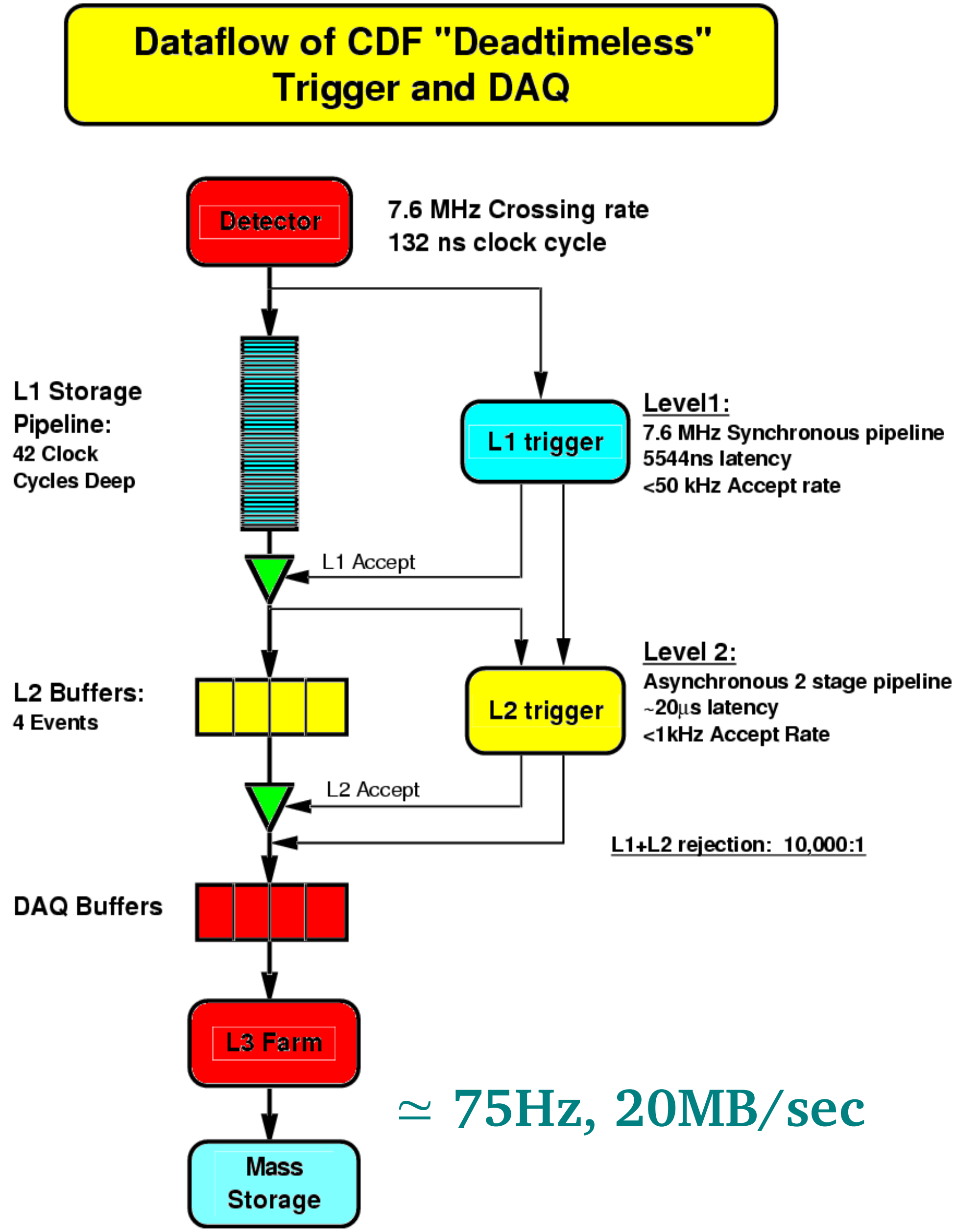
- Almost completely replaced to operate with shorter bunch spacing (132 ns) and handle higher data volume and rate
- One of the biggest upgrade projects for CDF
- Unique triggering capabilities for B physics



- Front-end and trigger electronics are housed in ~125 VIPA VME crates, 21 slots 9U x 400mm. ~ Half on detector, ~ half in counting rooms
  - Over 1700 main modules of about 60 types (+ >400 spares)
  - Over 1000 transition (I/O) modules of about 25 types
  - 60 - 6U Eurocard crates with >700 modules for Showermax readout and clock system
  - Over 25000 daughter boards

Trigger Overview

- **Level 1 (5.5μs latency) :**
  - Every front-end system stores data for 42 crossings
  - "Hardware trigger"
  - 50kHz accept rate (currently 12kHz)
  - On L1 accept, data is stored in one of four L2 buffers. Si readout starts.
- **Level 2 (asynchronous):**
  - Nominal 20μs decision time
  - "Mostly hardware" trigger
  - Trigger algorithms run on custom Alpha boards (up to 4)
  - 300Hz accept rate ($\rightarrow$ 1kHz)
  - Event readout starts on L2A
- **Level 3:**
  - $\simeq$ 250 dual-CPU Linux boxes
- *"Deadtimeless"*: DT only incurred when all L2 or DAQ buffers are full



$\simeq$ 75Hz, 20MB/sec

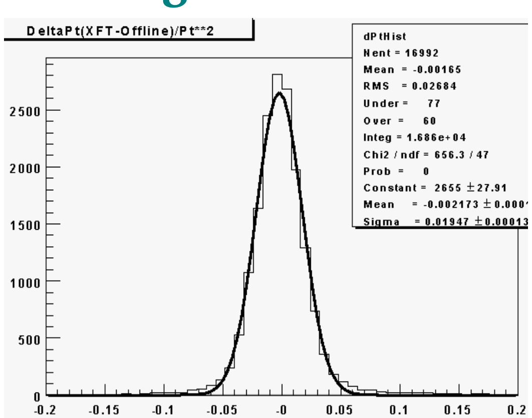
L1: eXtremely Fast Tracker

- Level 1 consists of custom hardware, fully pipelined, uses presently information from central drift chamber, calorimeters, muon systems, luminosity detectors
- Multi-object triggers and matching between tracks and calorimeter objects / muon stubs

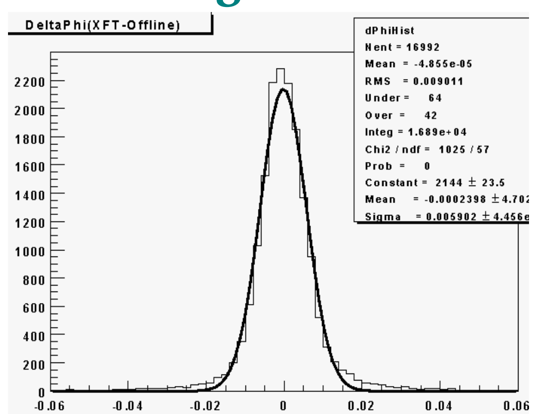
- **XFT provides high efficiency/purity track trigger on Level 1**
- XFT receives prompt/delayed hits, finds segments in axial superlayers, links segments to tracks
- XTRP system sends tracks to L1 muon, L1 calorimetry, and L1 track trigger, and upon L1A to L2 systems
- Resolution comparable to offline tracks

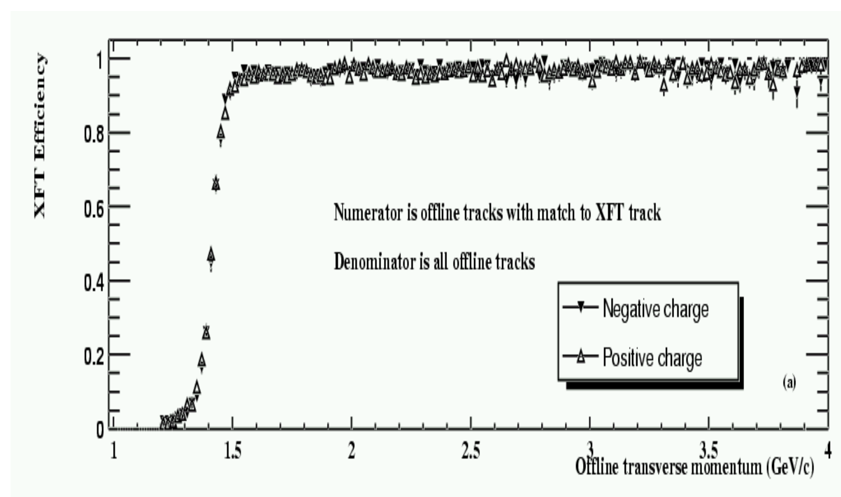
Plateau efficiency > 96%

$\Delta pt/pt^2$ = 0.016 GeV^{-1}
Design: 0.02 GeV^{-1}



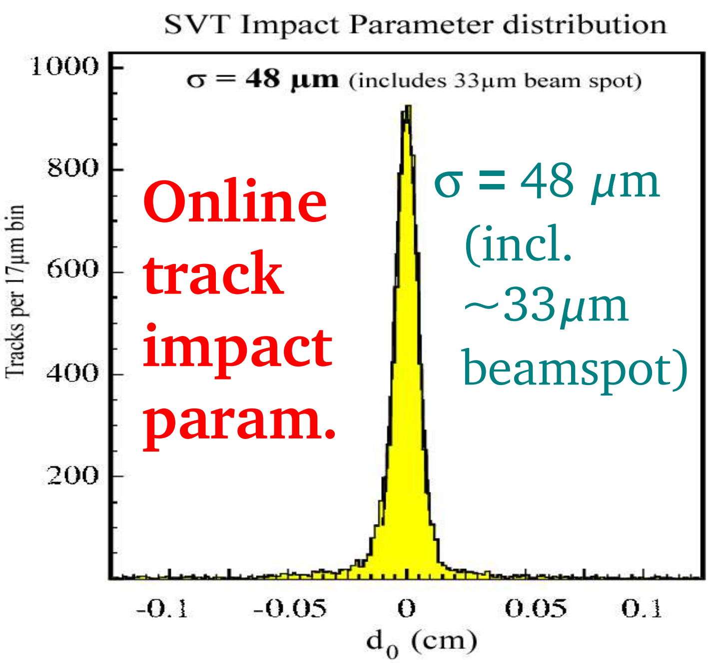
$\Delta\phi$ = 5 mrad
Design: 8 mrad

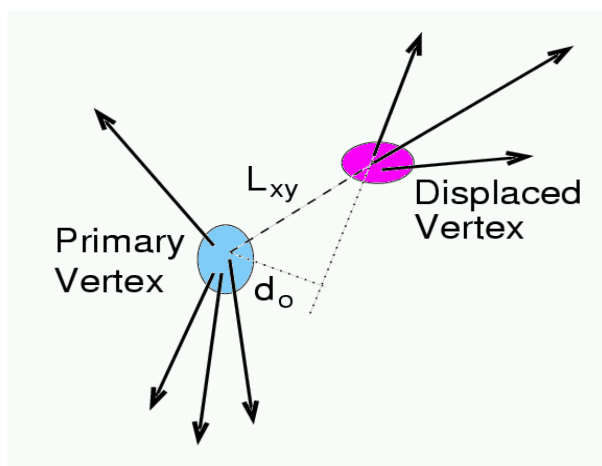




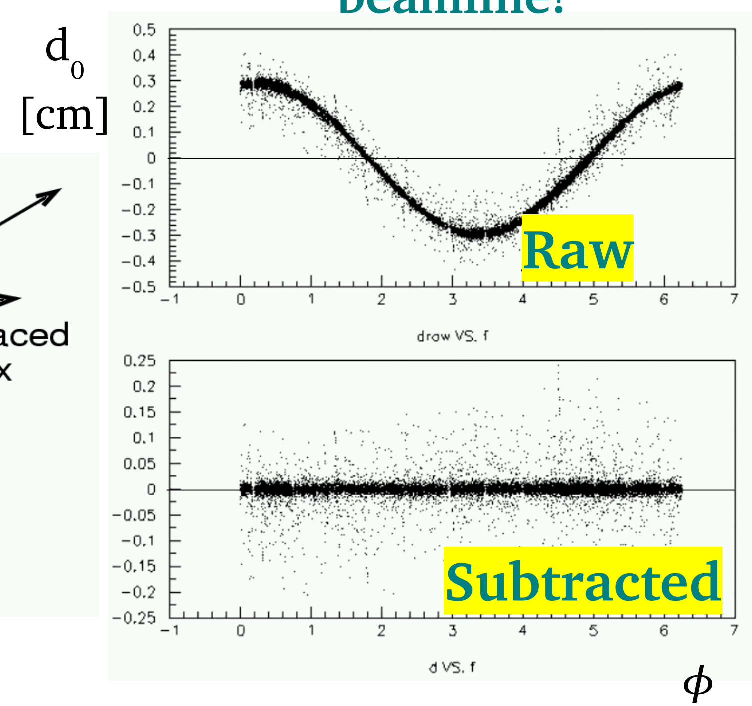
L2: Silicon Vertex Tracker

- Level 2 uses additional/refined information from calorimeter (clusters, isolation), muon systems and tracking (improved matching)
- Major rate reduction from revolutionary **displaced vertex trigger (SVT)**
- ~150 VME boards find and fit Silicon tracks, with offline accuracy, in a 15μs pipeline
- Combines Silicon hits with L1 tracks (XFT)





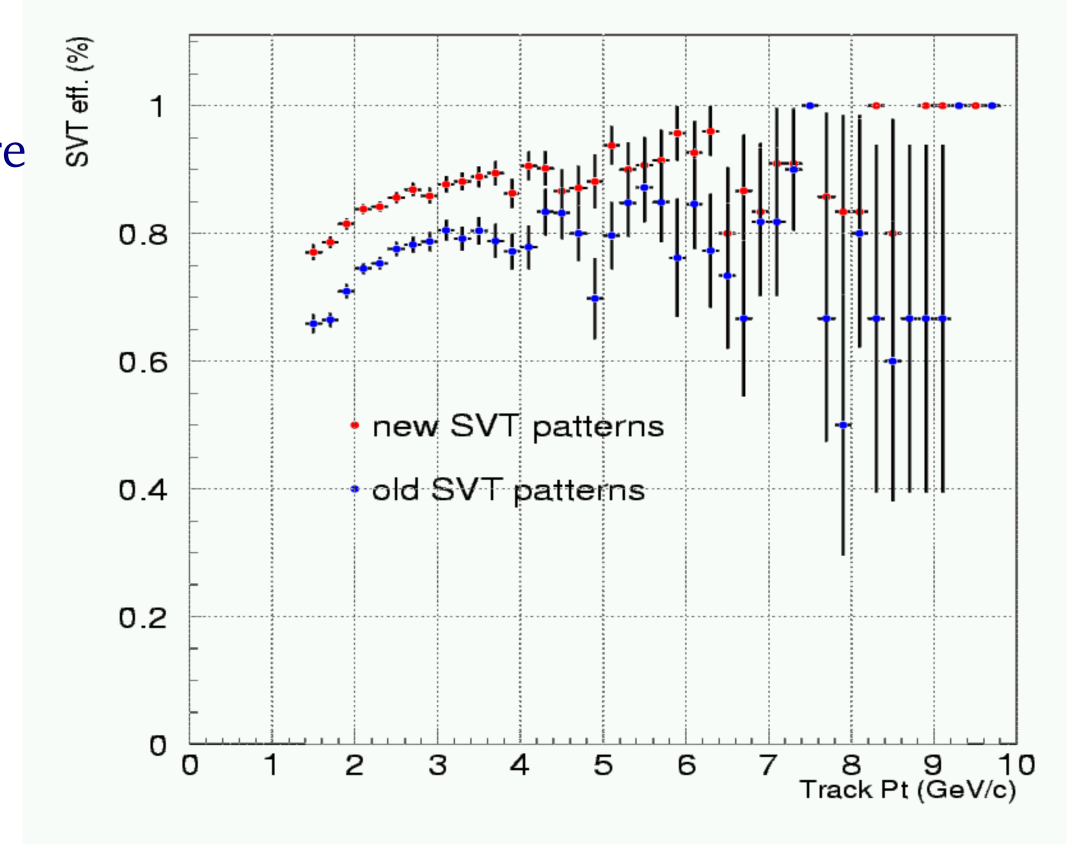
Online fit and subtraction of beamline!



Silicon Vertex Tracker cont.

- Many important physics signatures involve b quarks: Higgs searches, top studies, constraining CKM matrix, ...
- Allows purely hadronic B trigger, e.g. $B^0 \rightarrow \pi^+\pi^-$, $B_s \rightarrow D_s \pi$
- Lower thresholds for multi-object triggers involving B's
- Cut at $d_0 > 100/120\mu m$ (compare $c\tau \sim 460\mu m$ for B decays)

- Efficiency has been improving as more of the Silicon is included
- Additional improvements by refined pattern matching algorithm



TTT Topics

B-physics

Charmed decays

$B^+ \to \overline{D}^0(3)\pi^+, \overline{D}^0 K^+$
$B^0 \to D^{(*)-}\pi^+$
$B_s^0 \to D_s^-(3)\pi^+$
$\Lambda_b^0 \to \Lambda_c^+\pi^-$

Charmless 2-body

$B^0 \to \pi^+\pi^-, K^+\pi^-$
$B_s^0 \to K^+K^-, \pi^+K^-$
$\Lambda_b^0 \to p^+\pi^-, p^+K^-$

Charmless multibody

$B^+ \to \pi^+\pi^-\pi^+, K^+\pi^-\pi^+, \phi K^+$
$B^0 \to \phi K^{(*)0}$ $B_s^0 \to \phi\phi$

Short-term focus on observation and branching ratios.
Follow-up with Lifetimes, ~~CP~~, mixing

Charm physics

Cross-section

$$\frac{d\sigma}{dp_T}(D^0, D^{*+}, D^+, D_s^+)$$

Branching ratios

$D^0 \to \pi^+\pi^-, K^+K^-$

D⁰ mixing

$\Gamma(D^0 \to CP \text{ vs non} - CP)$

$D^0 \to K^+\pi^-$

Direct CP violation

$D^0 \text{vs} \overline{D}^0 \to \pi^+\pi^-, K^+K^-$
$D^+ \text{vs} D^- \to \pi\pi\pi, KK\pi$

Rare decays

$D^0 \to \mu^+\mu^-$ $D^+ \to \mu^+\mu^-\pi^+$

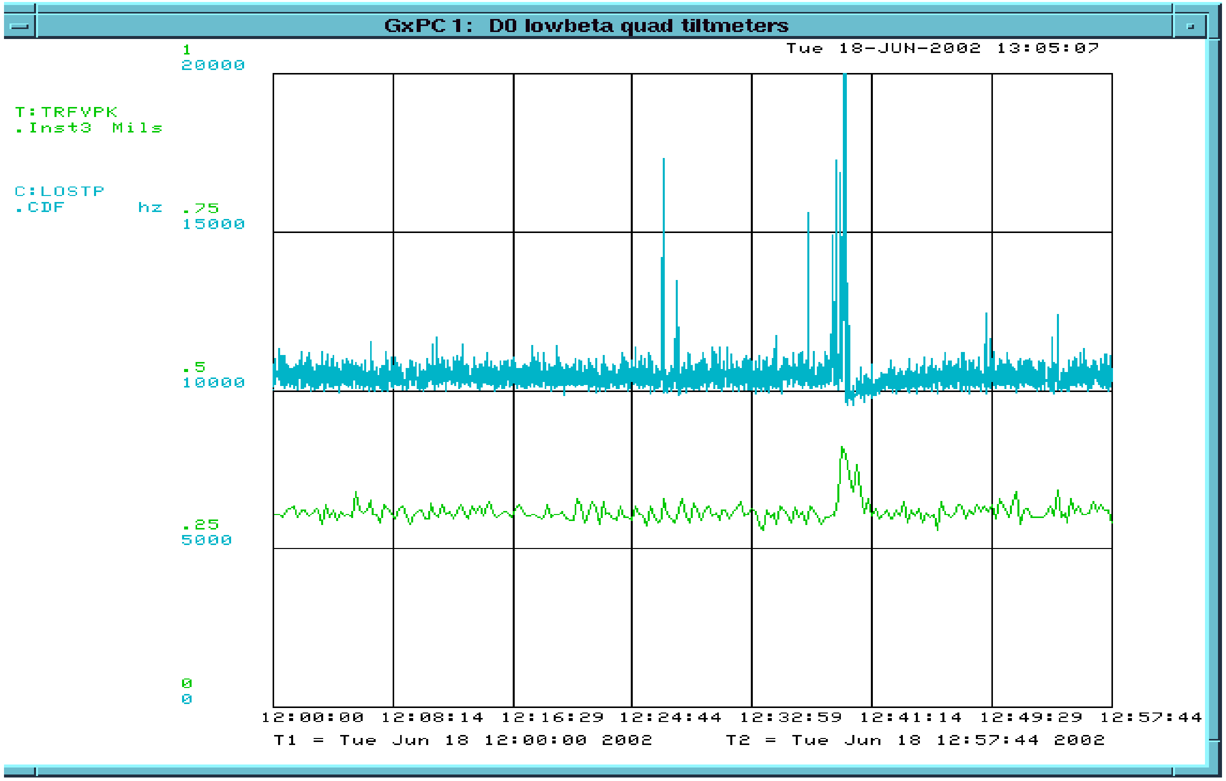
D**

$D_1^0, D_2^{*0} \to D^{*+}\pi^-$

First (?) Run II Result

- June 18, 12:37: Earthquake (mag 5.0) near Darmstadt ... *(Indiana)*
- 12:39 spike in proton losses and vibration monitor at F0
- Delay fits the propagation velocity data posted by the US Geological Survey

(CDF shields D0 from proton losses)



Data Taking and Operations

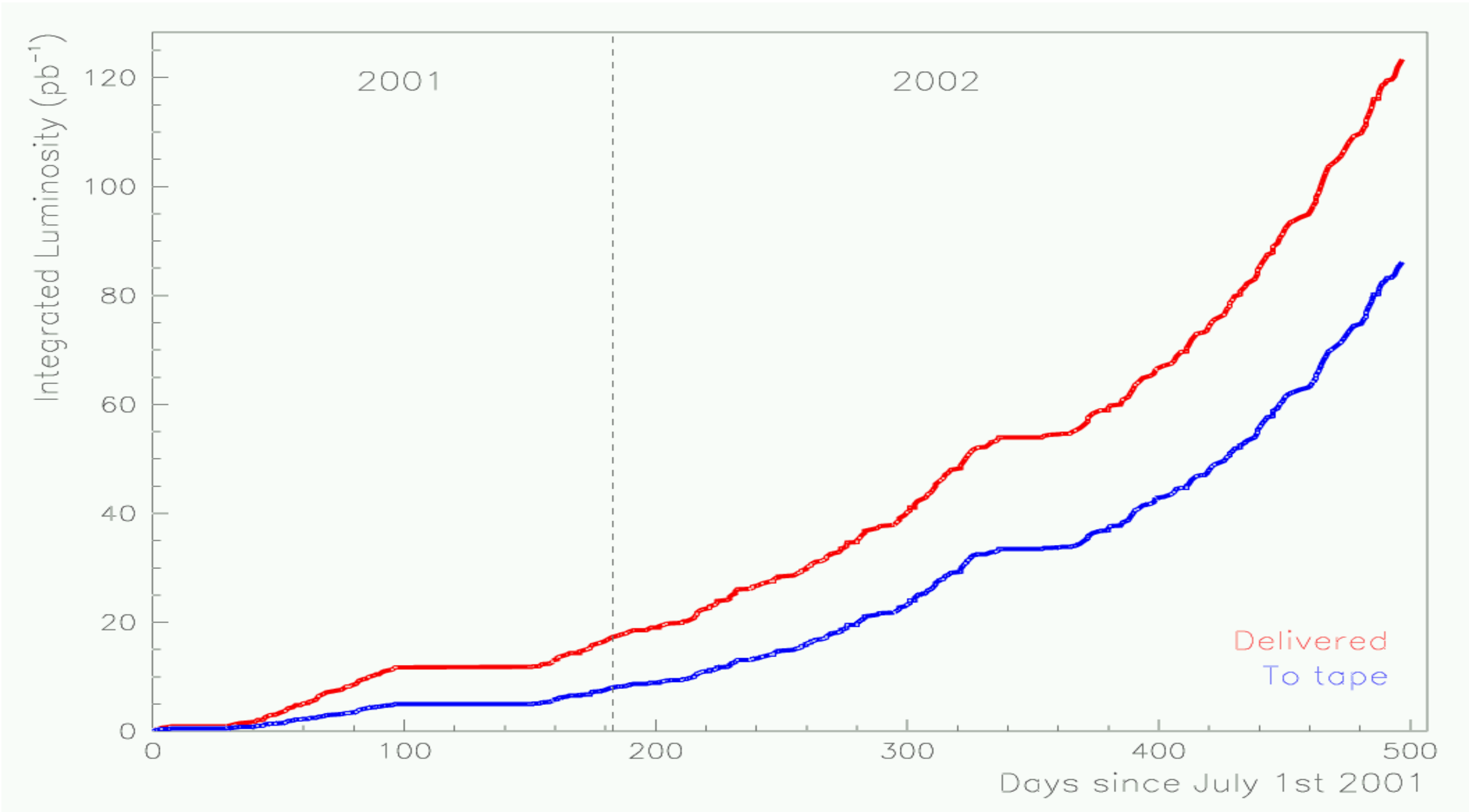
- *"Smooth running until something breaks".* Major disruptions:
- Radiation induced power supply failures
  - Had to replace 43(!!) VME power supplies in the collision hall until June 2002
  - "St. Catherine's day massacre": lost 12 PS within a few hours
  - Caused by single event burnout in power MOSFET
  - Operating conditions on all PS have been changed for better radiation hardness
  - Will install (massive) additional shielding in next extended shutdown
- Silicon vulnerablilty
  - Lost 6 SVXII ladders during (radiation) incident March 30 this year (another one Sat.)
  - Since then extremely cautious operation, added interlocks (TeV RF etc.), attempts to reproduce in Booster radiation facility, ...
  - Still not out of the woods: presently limiting trigger to 12kHz (current line of thought: *at resonance frequency, mechanical stress due to Lorentz force causes wirebonds to break*)

Data Taking cont.

- As of yesterday, $\int L\,dt \simeq$ **123 pb^{-1} delivered, CDF wrote 86 pb^{-1} to tape**
- Since February 1st, took (in runs with physics trigger tables)

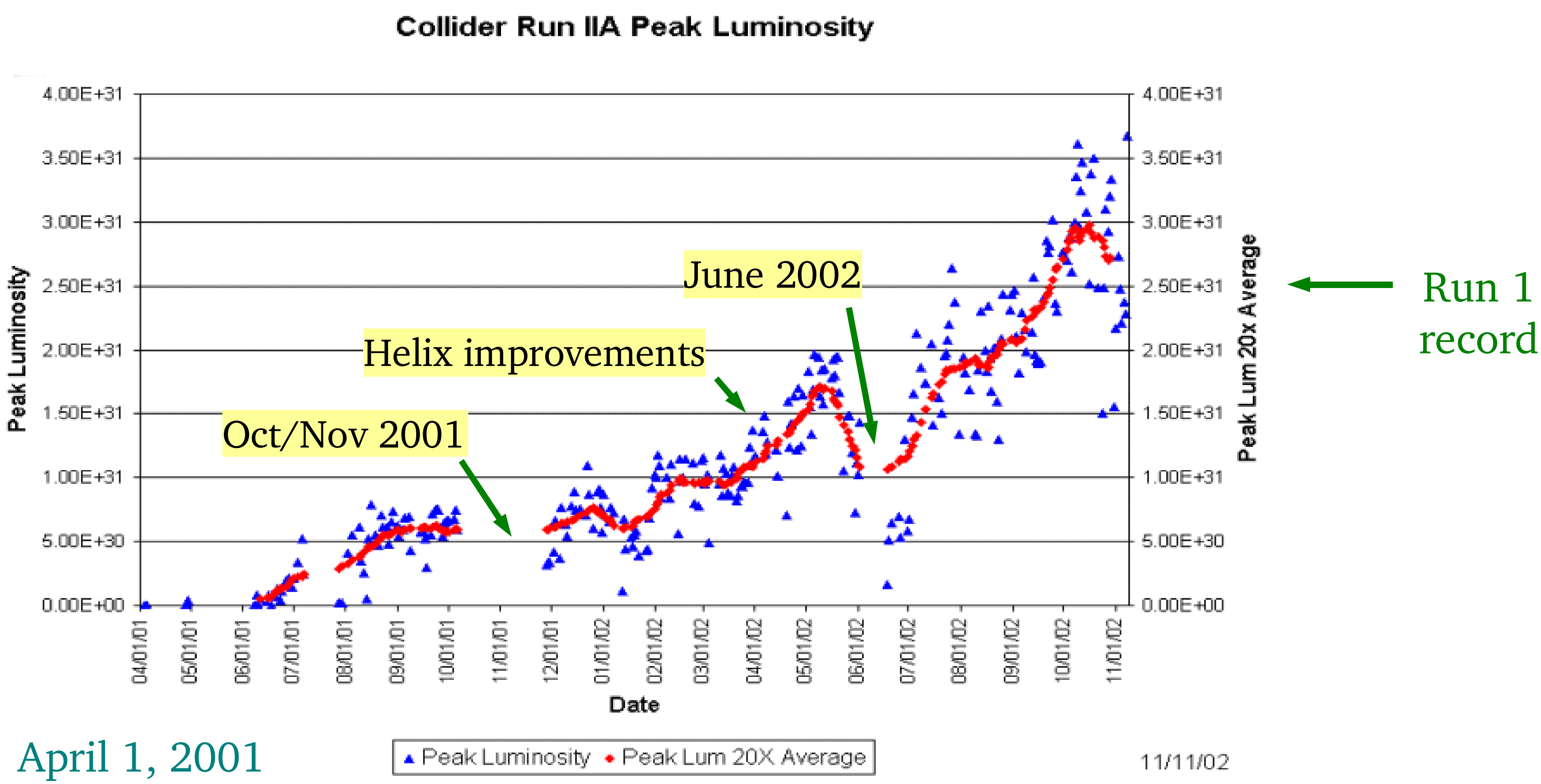
30,050,378,079	**L1 Accepts**	**Typical rates:**	**9-12 kHz**
919,765,247	**L2 Accepts**		**200-300 Hz**
166,941,919	**L3 Accepts**		**30-55 Hz**

- We collect ~ 1 Terabyte of data on a good day (typical store duration 15 hrs)

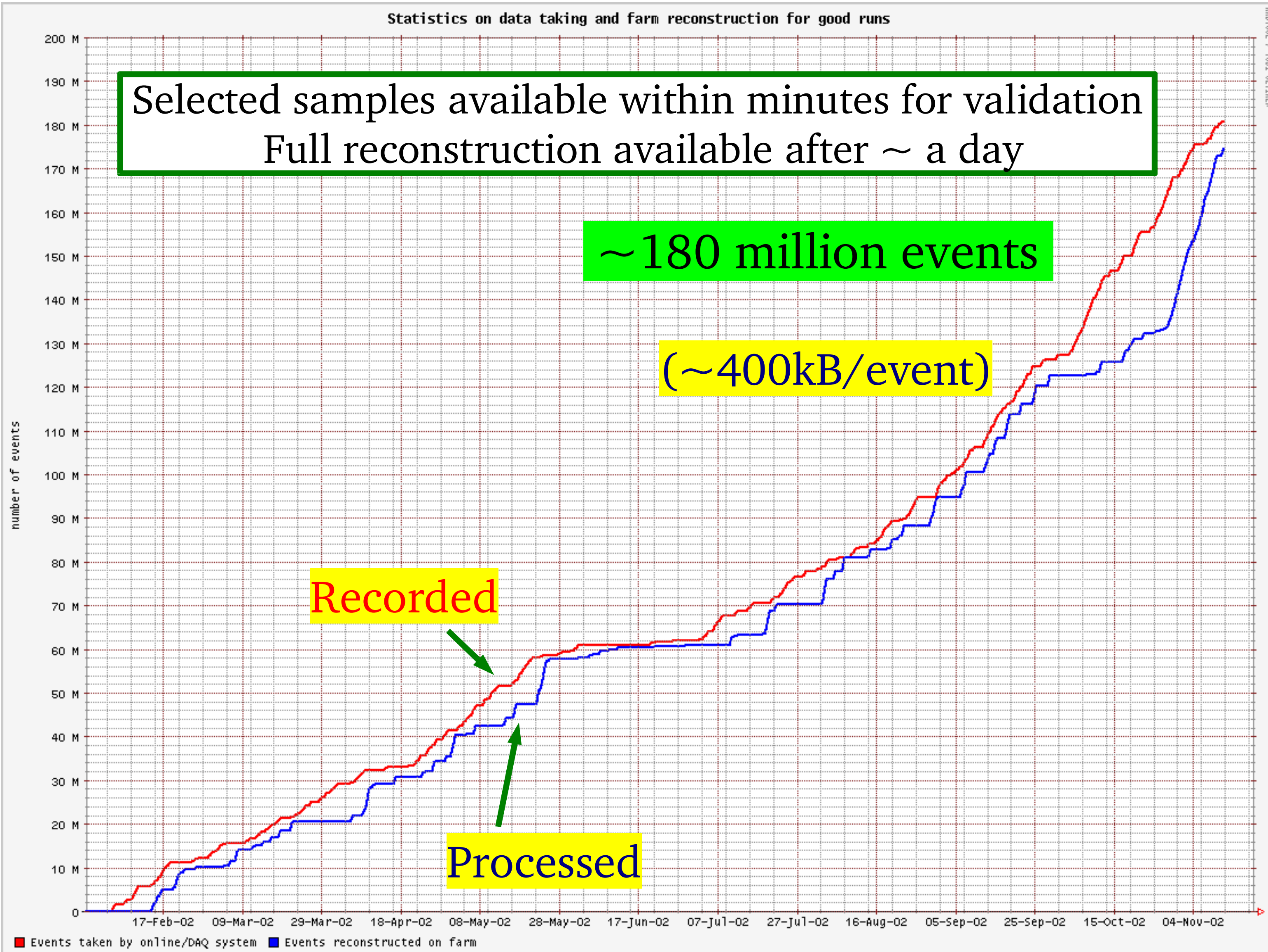


Data Taking cont.

- Shutdown in June: installed stochastic cooling tanks in accumulator, implemented new *antiproton unstacking lattice* in accumulator
- Next shutdown moved to January or (more likely) later, to allow the experiments to accumulate data

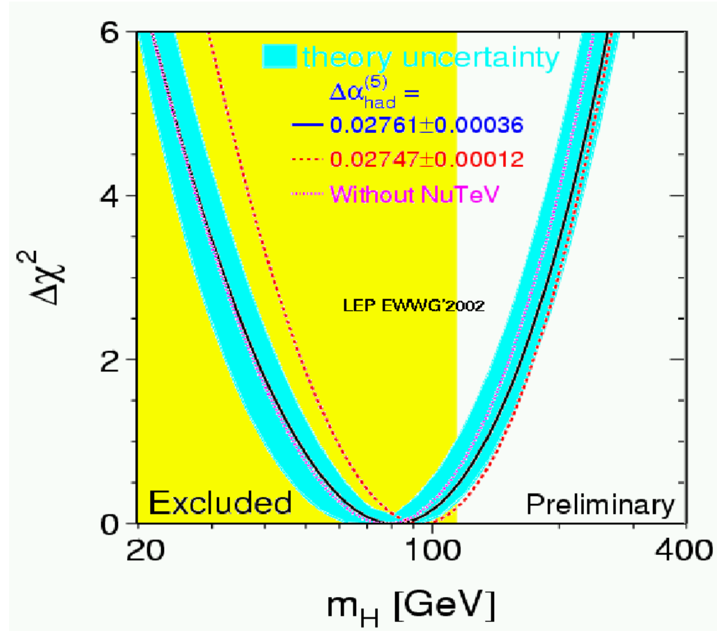


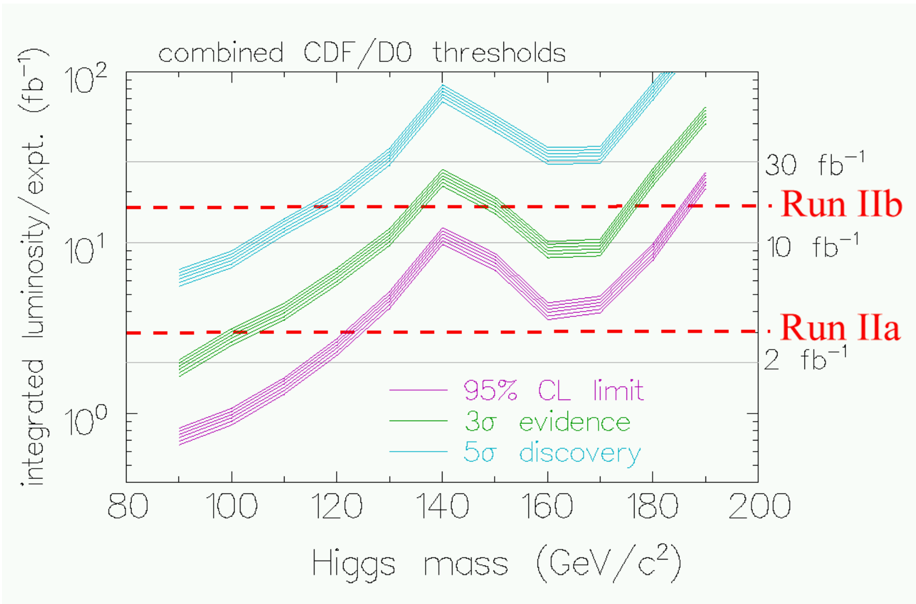
Data Taking cont.



CDF Run II Physics Goals

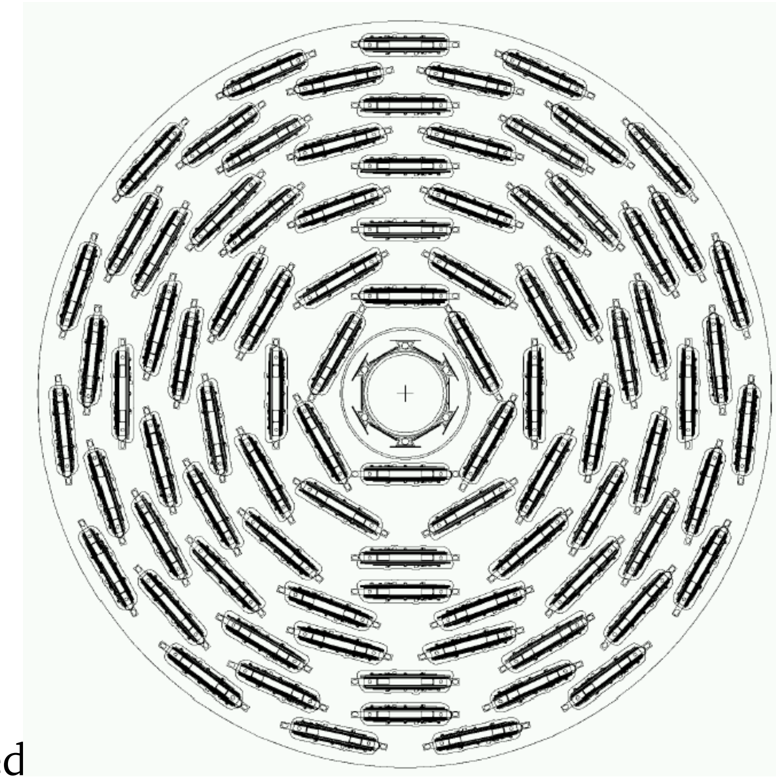
- Two main goals
  - Find the Higgs: 5σ discovery seems possible for low mass Higgs
    - Exclusion up to 180GeV with $\simeq$10 fb^{-1}
  - Direct evidence of something beyond the Standard Model, e.g. SUSY partners
- Precision top / electroweak measurements
  - E.g. Higgs Bounds from m_W and m_t
  - $m_t = 174.1 \pm 5.1$ GeV (Run I CDF+D0 comb.)
    $\rightarrow \pm$ **4 (Run 2a)** / $\pm$ 2 **(Run 2b) GeV**
  - $m_W = 80.452 \pm 0.062$ GeV
    $\rightarrow \pm$ 35 **(Run 2a)** / $\pm$ 20 **(Run 2b) MeV**
- B physics
  - CKM matrix and CP violation
  - B_s mixing
- … as well as more exotic fare
  - Large extra dimensions
  - Mini black holes





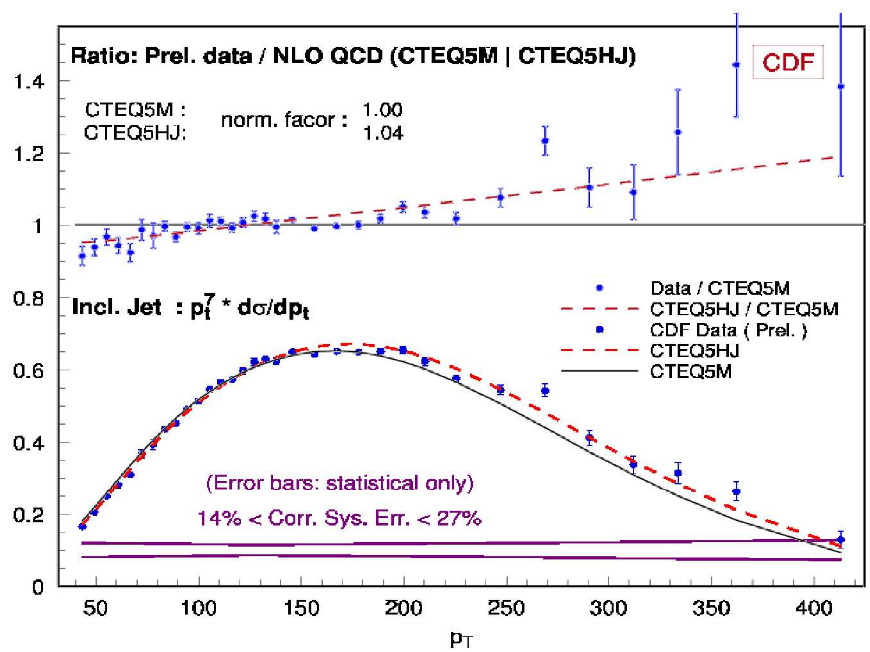
Run IIb Upgrade (2005)

- We haven't even started to build the detector to go well above 2 fb^{-1}
- A major upgrade will be required to maintain our capabilities throughout Run II
- All Silicon detectors except ISL will need to be replaced after ~ 5 fb^{-1}!
- Much simpler design than Run IIa
- Trigger and DAQ upgrades
  - ♦ Add stereo capability to XFT (**"3D XFT"**) for better rejection at L1, mass cut at L2, reduced fake rates
  - ♦ The **Level 2 decision system** will have to be replaced (Alpha, "MagicBus")
  - ♦ To sustain 1kHz and more L2 Accept rates (= readout rates), the **event builder** (built around ATM switch) needs to be upgraded
  - ♦ For the same reason, the **COT TDC system** will likely be replaced

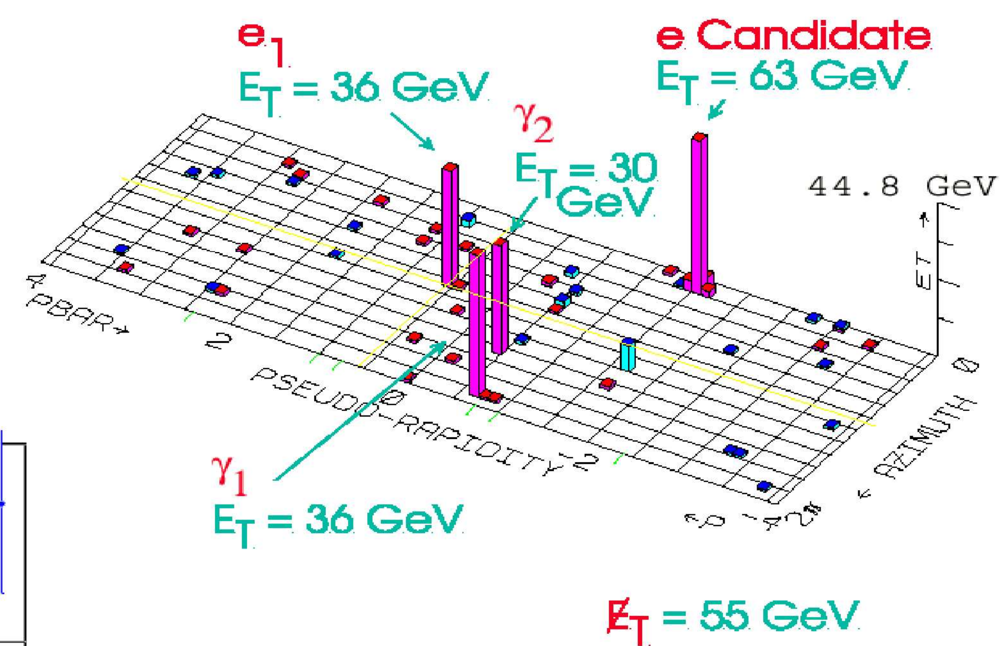


CDF Run II Physics Goals

Follow up on Run I anomalies!



$ee\gamma\gamma\not{E}_T$ Candidate Event



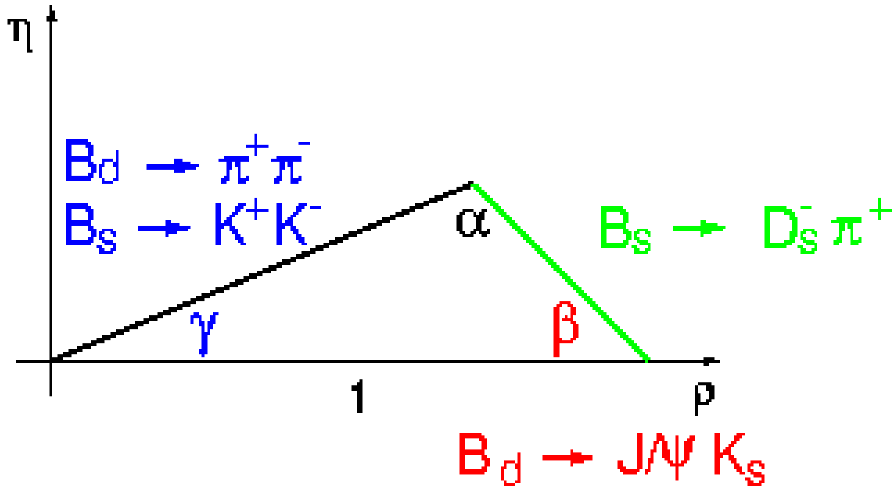
- ee $\gamma\gamma$ MET event
- High E_t inclusive jet cross section
- *"Superjets"*: excess in W+2,3 jet events with double b-tags

CDF Run II B Physics Goals

"High profile" analyses

- CP violation (oh well...)
  - Improved measurement of $\sin(2\beta)$ in $B^0 \to J/\psi\, K^0_S$: $\simeq$ 20000 events in 2 fb^{-1}

    $\sigma(\sin 2\beta) \simeq 0.05$



- B_s mixing in $B_s \to D_s\pi^+ / D_s\pi^+\pi^-\pi^+$, sensitivity up to about

  $x_s \simeq 60$ ($\simeq$75000 events)

  $x_s \simeq 30$ in semileptonic decays

  ($x_s = \Delta m_s / \Gamma_s$)

- Measurement of γ in $B^0_d \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$ decays
  - Use of both decays reduces the influence of penguins
  - Assuming S/B = ½ and $\Delta m_s = 30\ ps^{-1}$ events: 5000 ($\pi^+\pi^-$) / 10000 (K^+K)

    $\sigma(\gamma) \simeq 7^0$

B Roadmap

- Stage I ($\int L\,dt \simeq 50\ pb^{-1}$) ***now***
  - Lifetime Measurements
  - Cross sections, branching ratios, masses
- Stage II ($50\text{-}200\ pb^{-1}$) ***Spring / Summer 2003***
  - First Run II $\sin(2\beta)$ measurement
  - First B_s mixing measurement
  - B_s, Λ_b lifetimes and masses
  - Charmonium polarization
- Stage III ($>200\ pb^{-1}$)
  - B_s, B_c, Λ_b properties
  - Rare decays
- And: add a broad spectrum of Charm topics - ***now*!**

Why B Physics at the Tevatron?

- Huge cross section
  - $\sigma(\text{ppbar} \rightarrow \text{bbar})$ $\simeq$ **150 μb** at $\sqrt{s}$ = 2 TeV (15 kHz at L = $10^{32}\text{cm}^{-2}\text{s}^{-1}$)
    50 μb for $|\eta|<1$
  - $\sigma(e^+e^- \rightarrow \text{bbar})$ $\simeq$ **7 nb** at Z^0
  - $\sigma(e^+e^- \rightarrow \text{bbar})$ $\simeq$ **1 nb** at $\Upsilon(4S)$
- Produce bottom mesons with all flavor combinations as well as bottom baryons
  - B_c, Λ_b, Σ_b, ... no competition from B factories
- Multipurpose detector capable of reconstructing many B final states
  - Very large tracking volume
- DAQ / trigger / particle ID are tailored for B physics!
  - Up to 50kHz Level 1 accept rate!
  - Trigger on displaced vertices at Level 2
  - Time-of-Flight detector for K tagging

$\sin(2\beta)$

- Run I luminosity and silicon vertexing sufficient for measurement of $\sin(2\beta)$ in B_d mixing
- CDF published result

  $\sin(2\beta) = 0.79 \pm 0.39 \pm 0.16$

- CDF result (2001)

  $\sin(2\beta) = 0.91 \pm 0.32 \pm 0.18$

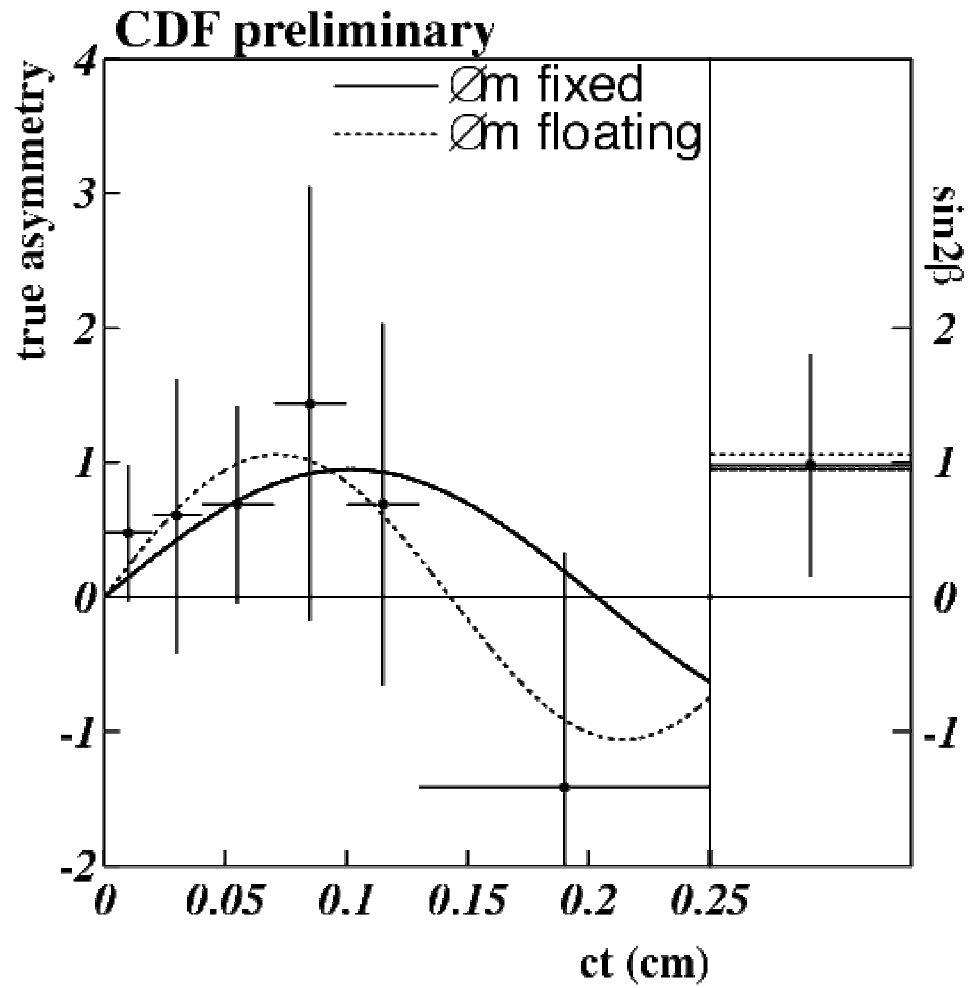
  Measured using decay channels $B_d \rightarrow J/\psi\ K_s^0$, $B_d \rightarrow \psi(2S)\ K_s^0$

- Babar

  $\sin(2\beta) = 0.74 \pm 0.07 \pm 0.03$

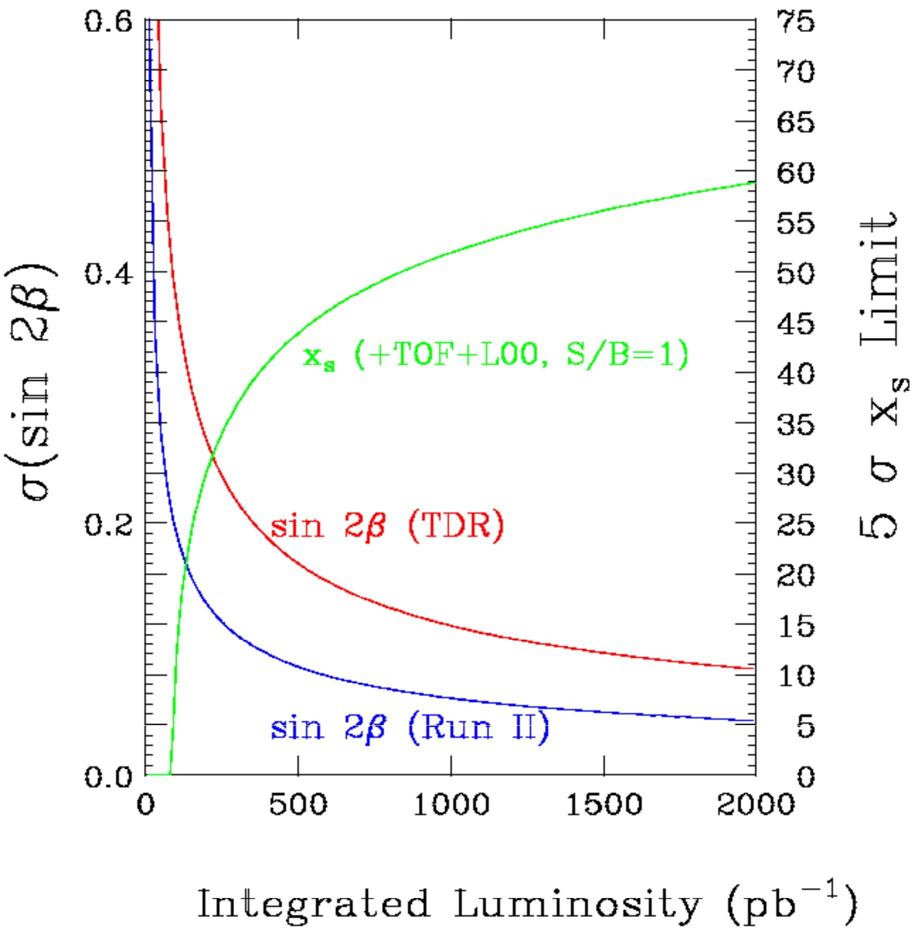
- Belle

  $\sin(2\beta) = 0.72 \pm 0.07 \pm 0.04$



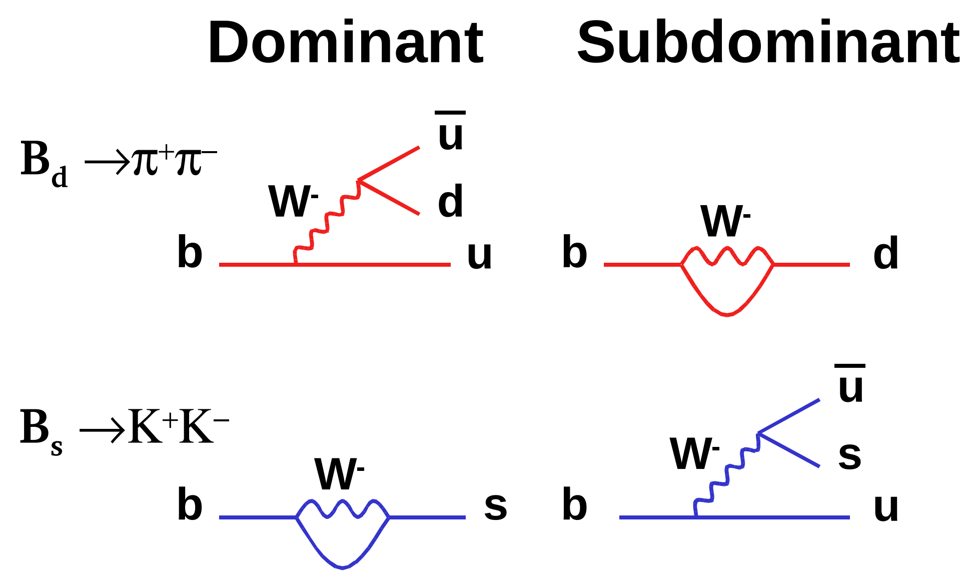
B_s Mixing

- Reconstruct B_s decays using fully hadronic and semileptonic decay channels.
- Measure $x_s = \Delta m_s / \Gamma$
- With 2 fb^{-1} should cover full range of theoretically predicted values for x_s
- Afterwards, can search for CP violation in the B_s system
  ($B_s \rightarrow J/\psi\ \phi$)
  - Large window for non-SM physics.



Unitarity Angle γ

- Measure γ using combination of
  - $B_d \rightarrow \pi^+\pi^-$
  - $B_s \rightarrow K^+K^-$
- **Challenges**
  - Separation of $B_{d,s} \rightarrow \pi\pi$, πK, KK
  - Understanding penguin contributions (using both decays helps)
  - In addition there are interference amplitudes due to mixing



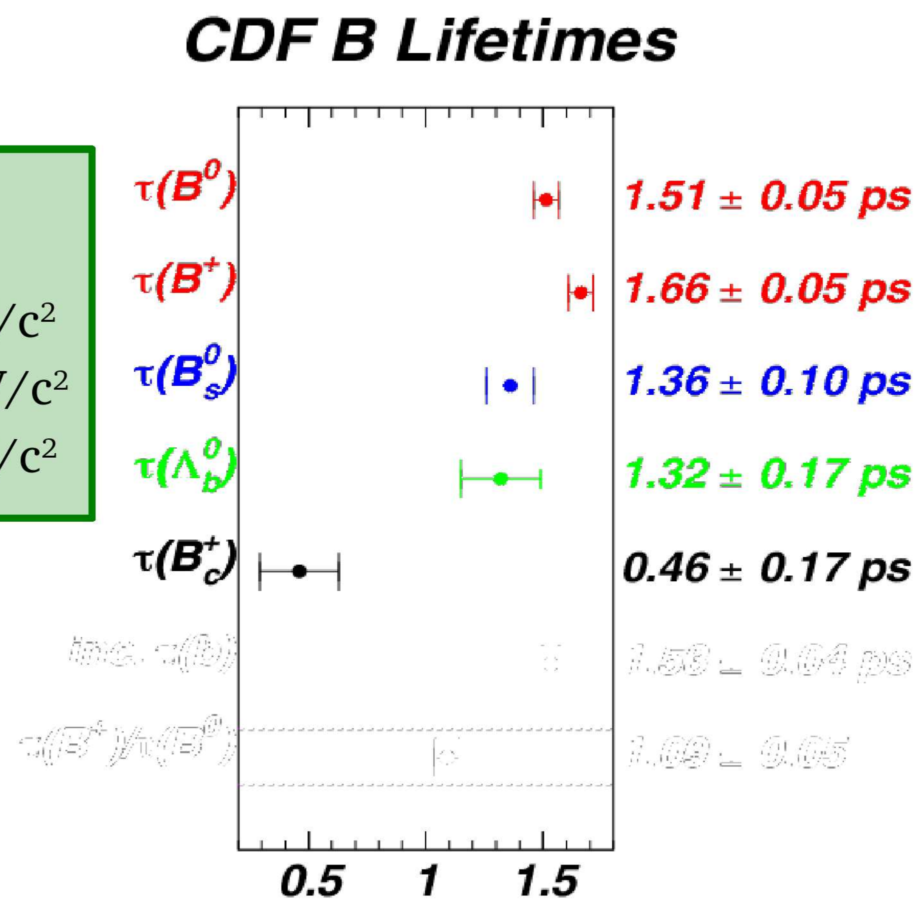
Decays related by d,s interchange

Meson / Baryon Spectroscopy

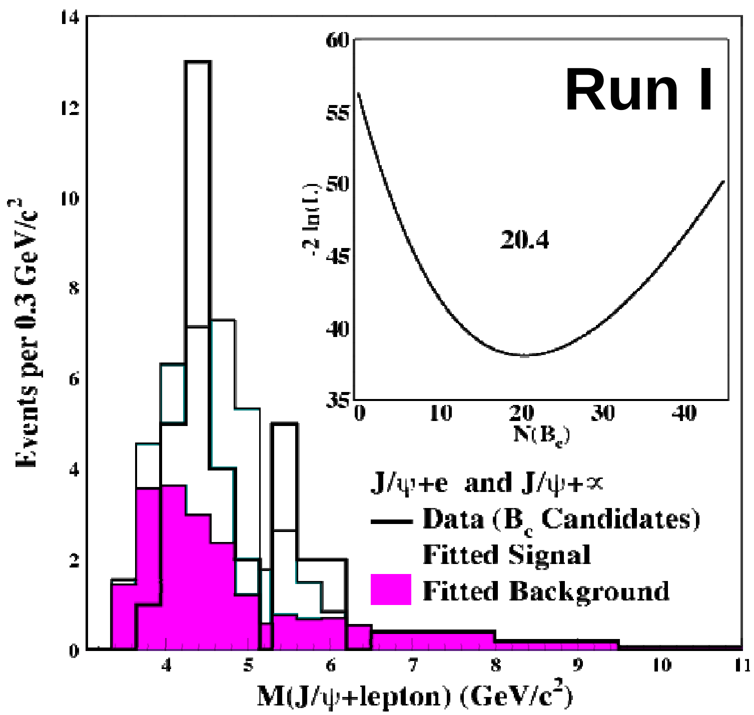
- Spectroscopy of B mesons with second generation quarks and B baryons currently available only at hadron colliders.

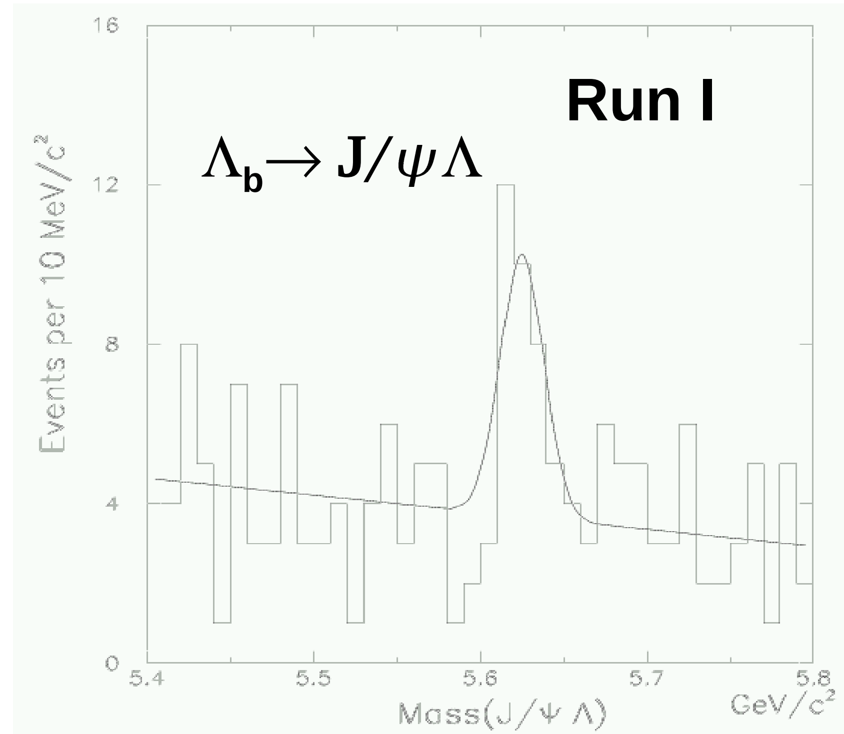
Run I Mass Measurements

$m(B_s) = 5.3699 \pm 0.0023 \pm 0.0013$ GeV/c^2
$m(\Lambda_b) = 5.621 \pm 0.004 \pm 0.003$ GeV/c^2
$m(B_c) = 6.40 \pm 0.39 \pm 0.13$ GeV/c^2



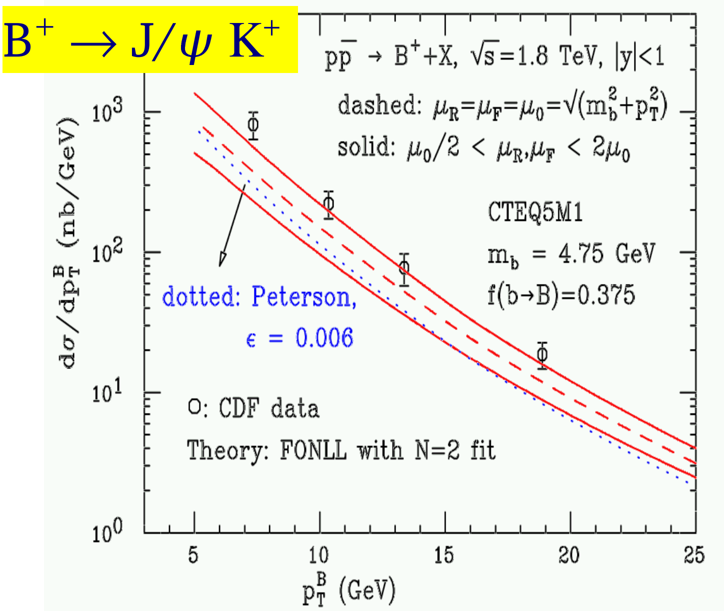
B_c and Λ_b

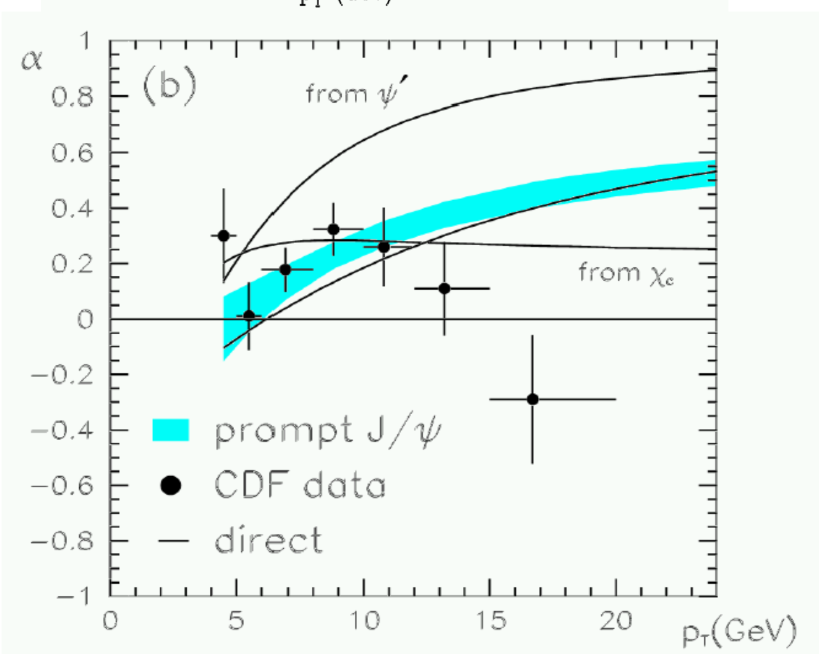




	$B_c \rightarrow J/\psi\ e/\mu$	(800)	$\Lambda_b \rightarrow J/\psi\ \Lambda$
Run IIa:	$B_c \rightarrow J/\psi\ \pi$	(400)	$\Lambda_b \rightarrow p\ D^0 \pi^-,\ D^0 \rightarrow \pi^+ K^-$
	$B_c \rightarrow B_s \pi$	(25)	$\Lambda_b \rightarrow p\ K^-$

b Cross Section, ψ Polarization



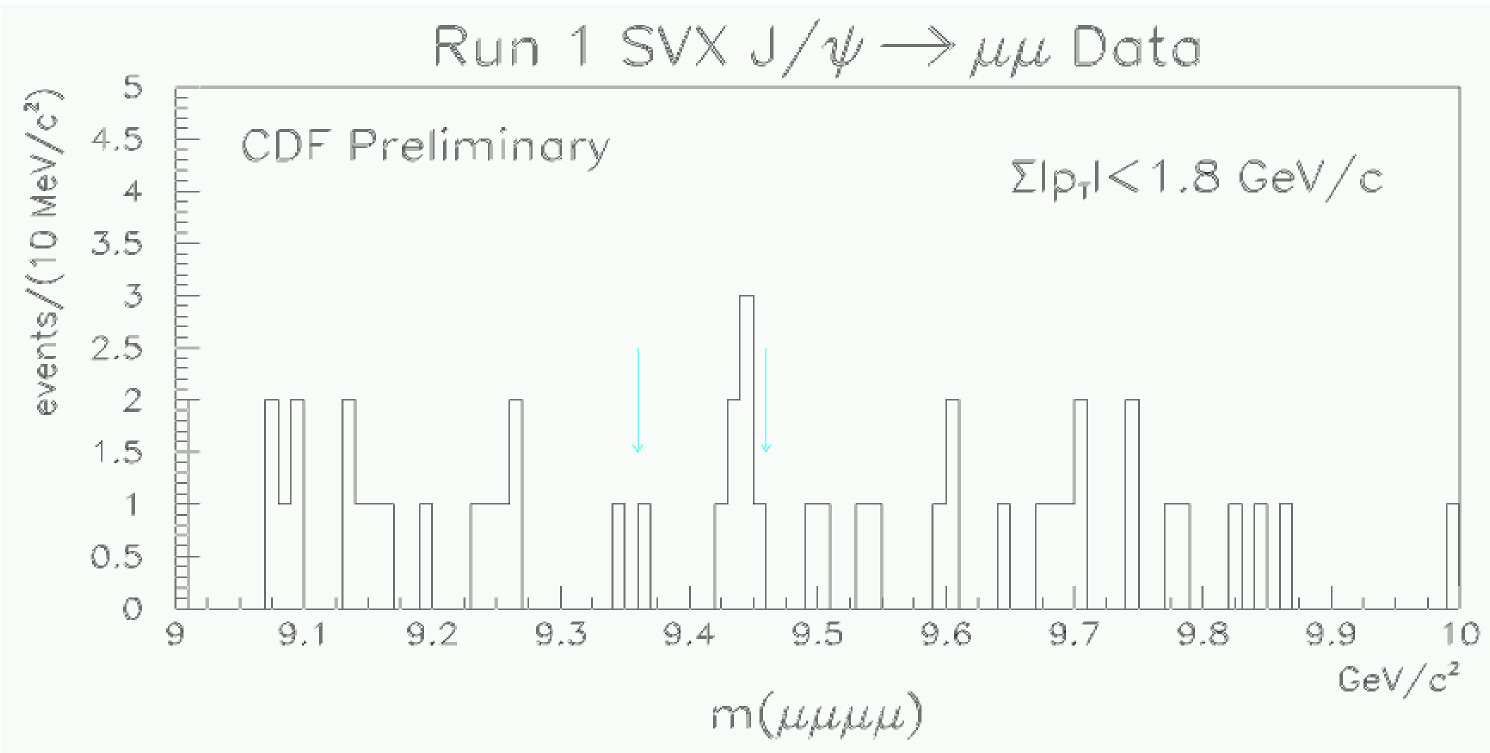


- Run I **b cross section measurements** are still somewhat high compared to NLO QCD
  - Improved treatment of fragmentation improved agreement data/theory
  - More precise and extended measurements in Run II
  - $b\bar{b}$ correlations to isolate higher order contributions

- **Measurements of Onium production** are another challenge to QCD
- Run I measurements of Charmonium production cross sections were high by up to 2 orders of magniture compare to models (Colour Singlet Model)
  - Inspired many theoretical developments (non-relativistic QCD, Colour Octet Model, ...)
- Also polarization measurements
  - Extend to higher p_t (predictions are more reliable)
  - Test models to describe high ψ cross sections

Search for η_b (new Run I result)

- Lightest member of the Bottomonium family - **good chance to be discovered early in Run II**
- Most promising decay mode is to J/ψ J/ψ
- Run I: found a 2.2 σ (1.5%) excess, using $\mu\mu\mu$+track search strategy
- Lower trigger threshold and improved acceptance will help in Run II

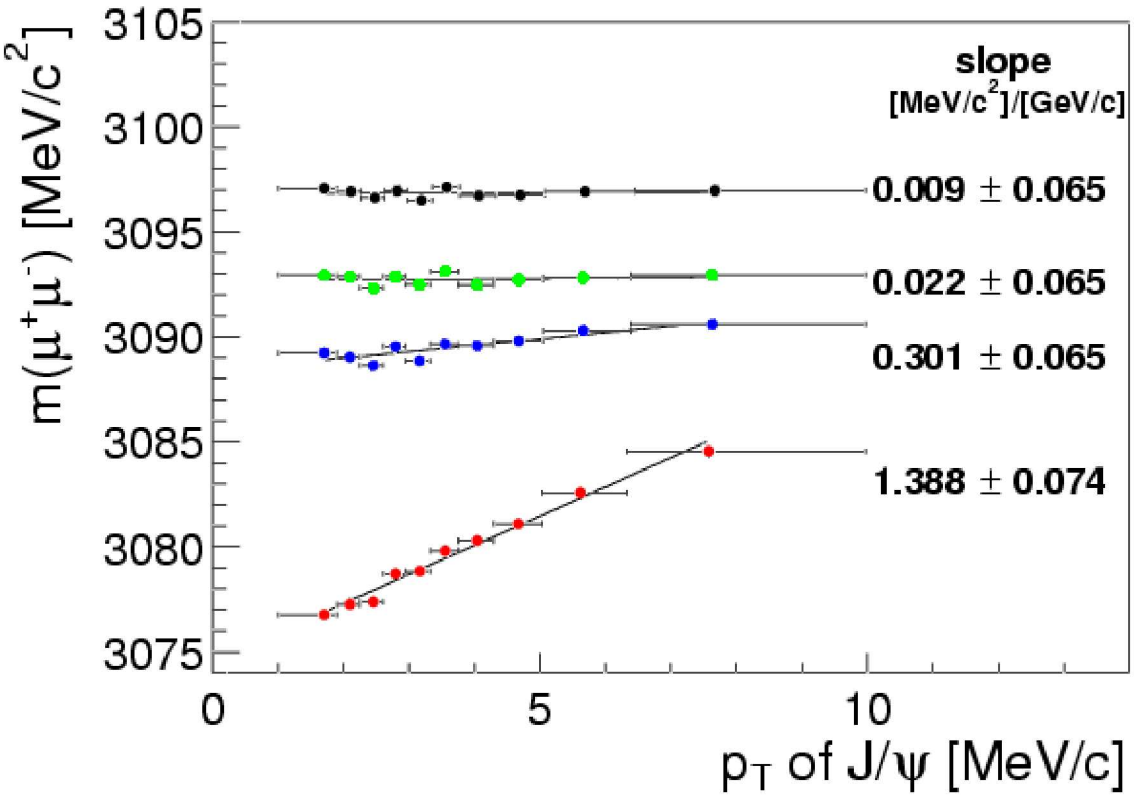


Back to reality!

Tracking: Energy Loss and B Field

For mass measurements, need excellent understanding of energy loss and magnetic field

Calibrate with J/ψ:



Reconstructed ψ mass as function of p_t

No corrections applied

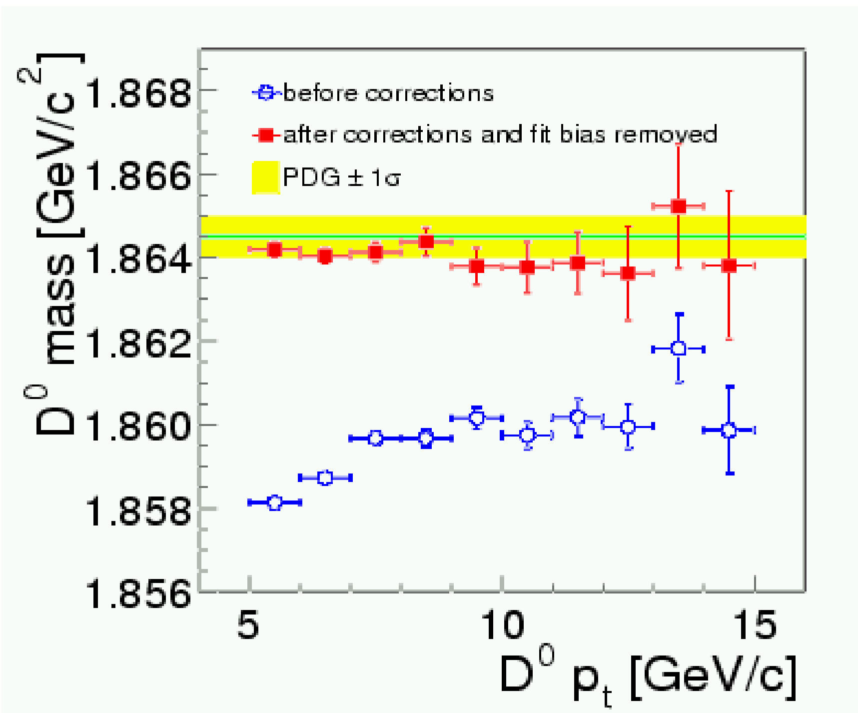
Geant material correction

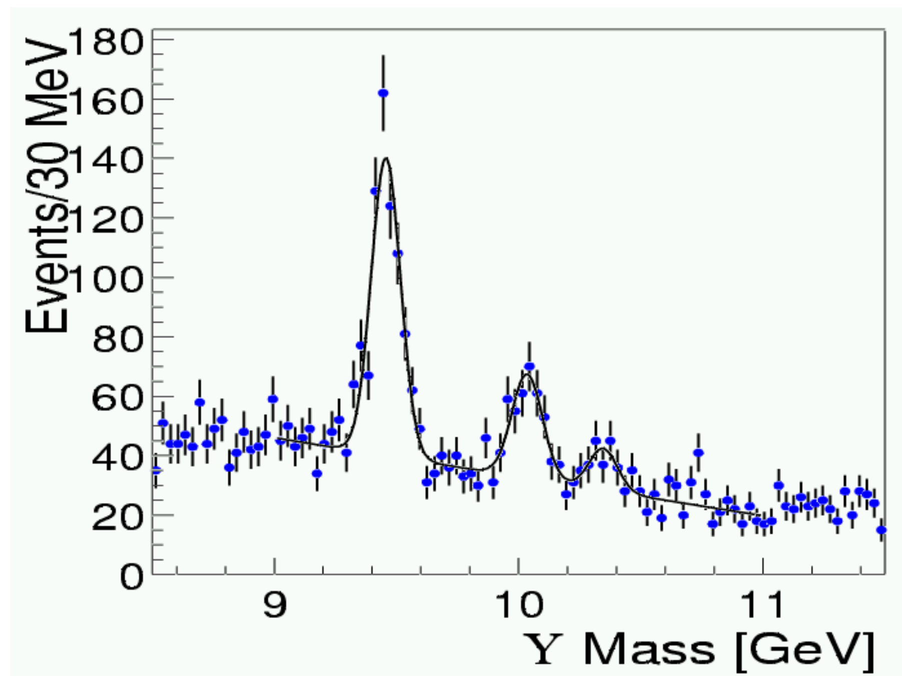
Tune material

Tune B field scale

Tracking Calibration Cont.

- Verify on independent samples
  - K_S^0, D^0, $D^{\pm}_{(s)}$, $B^{\pm}$, $\Upsilon(1S)$
  - Different momenta/masses
  - Look at p_t dependence, charge asymmetry, ...



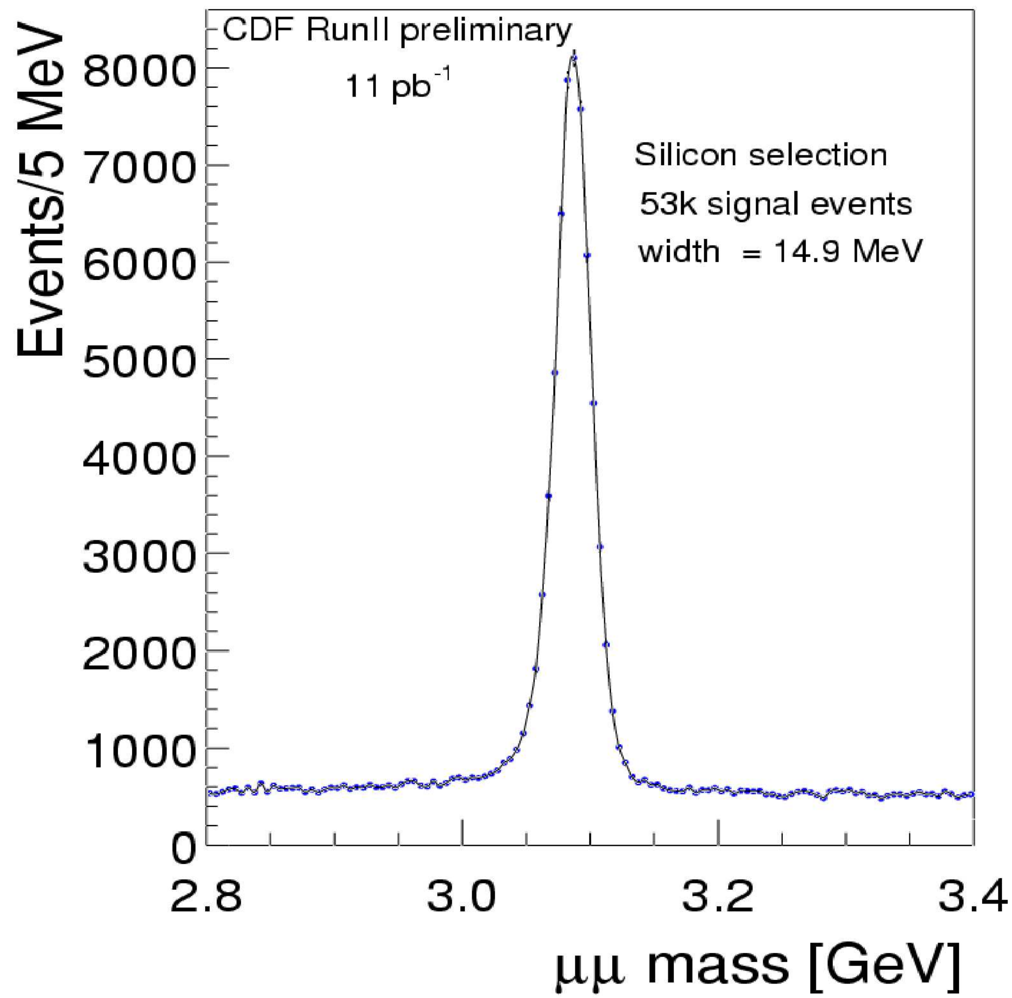


CDF	1864.25	± 0.06 (stat) MeV		CDF:	9461	± 5 (stat) MeV
PDG:	1864.5	± 0.5 MeV		PDG:	9460.30	± 0.26 MeV

Tracking cont.

CDF candle: J/$\psi \rightarrow \mu\mu$

- J/ψ width: 22 MeV (only COT)
  15 MeV (add Silicon)
- Visible cross section $\simeq$ 9nb (CMU only)
  - Sharp trigger turn-on $p_t > 1.5$GeV (Run 1: 2.2GeV, slow turn-on)
  - Di-μ trigger efficiency $\simeq$ 90%
- Invaluable for tracking studies, tuning, B physics, ...



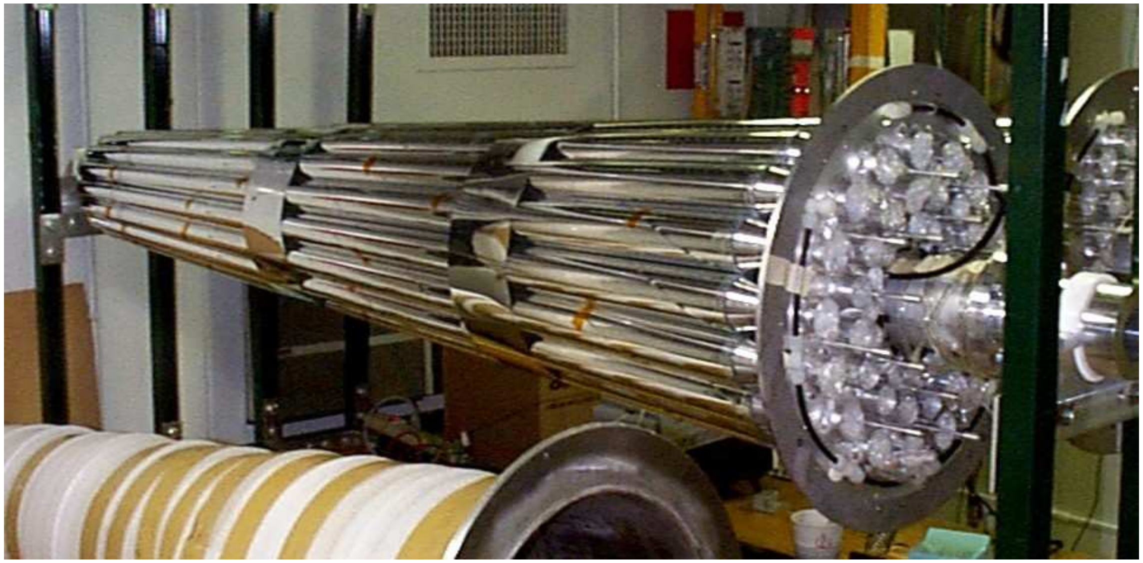
Note: "J/ψ" implies "J/$\psi \rightarrow \mu\mu$" for the rest of this talk

Luminosity Measurement

- Measure rate of inelastic $p\bar{p}$ interactions with Cherenkov Luminosity Counters
- Methods
  - "Hit-counting" method
  - Count empty crossings
  - High luminosity algorithms later on: particle counting, time clusters (have 100ps time resolution)

$$L = \frac{f_{BC}}{\sigma_{tot} \times \epsilon_{\alpha}} \times \frac{\langle N_H \rangle_{\alpha}}{\langle N_H^1 \rangle_{\alpha}}$$

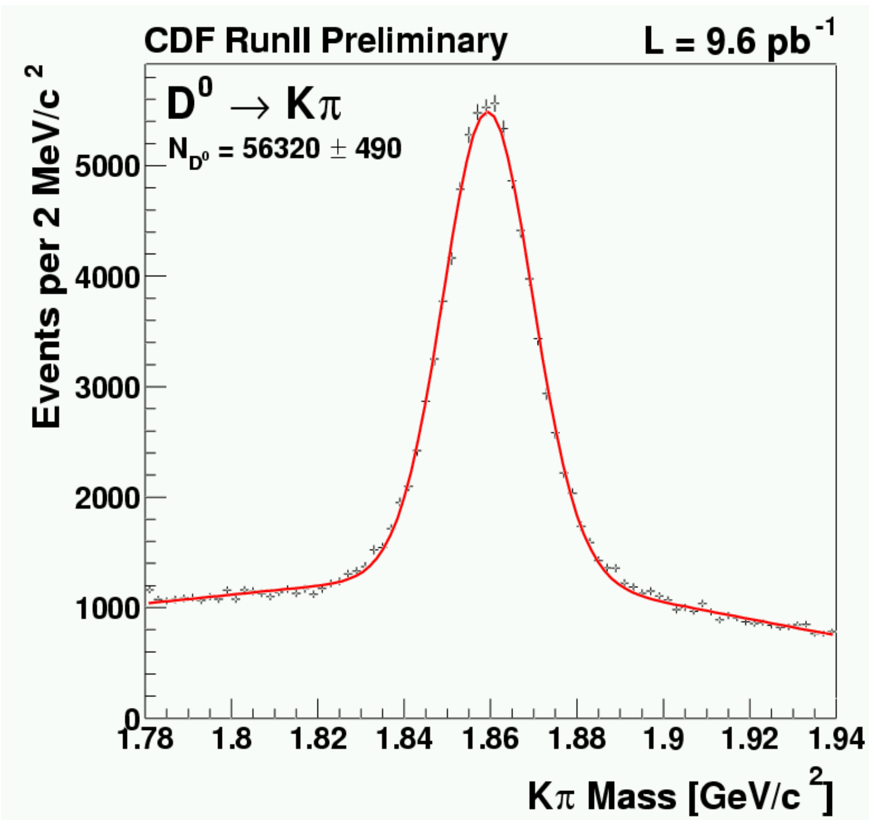
- Offline corrections: PMT gain drift, tighter cuts etc.
- Normalized using CDF's own inelastic cross section measurement - 8% higher than E811
- Total systematic uncertainty 5% now, dominated by CLC acceptance (simulation)
  - Not including total cross section uncertainty
- Verified to about 5% with $W \rightarrow e\,\nu$ cross section

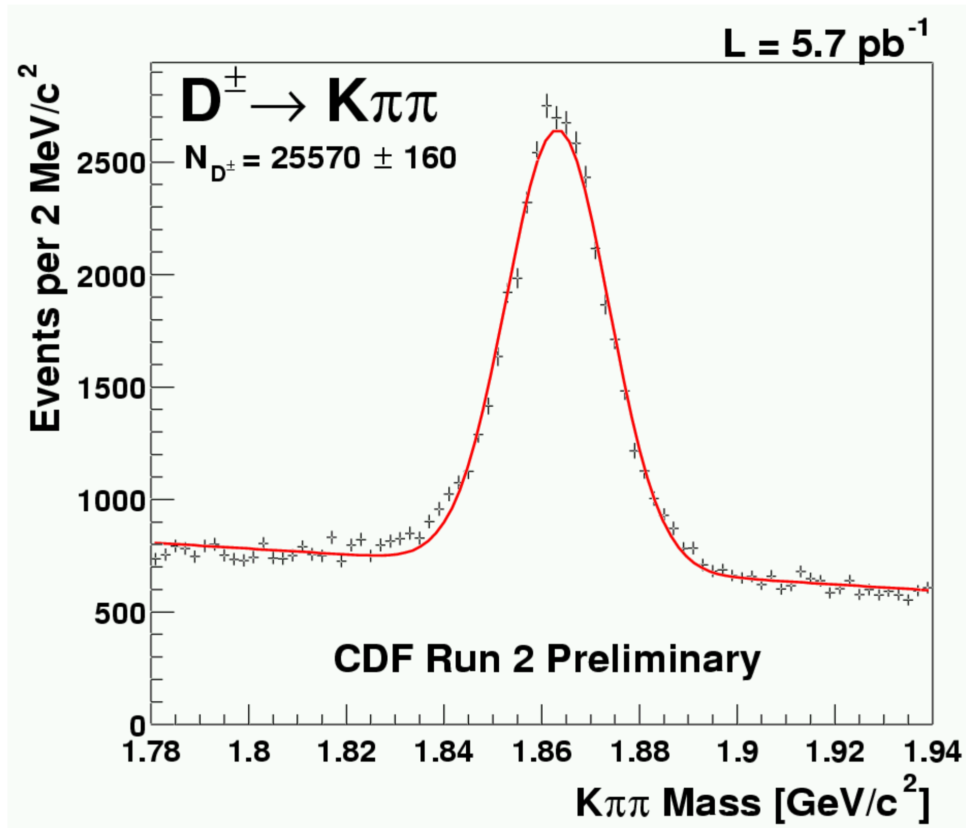


Charm Production

- Accumulating large amounts of charm final states through hadronic "B" trigger
  - L1: >2 XFT tracks, p_t > 1.5 GeV
  - L2: >2 SVT tracks, p_t > 2.0 GeV, d_0 > 120μm

No lepton was harmed in the making of these plots!

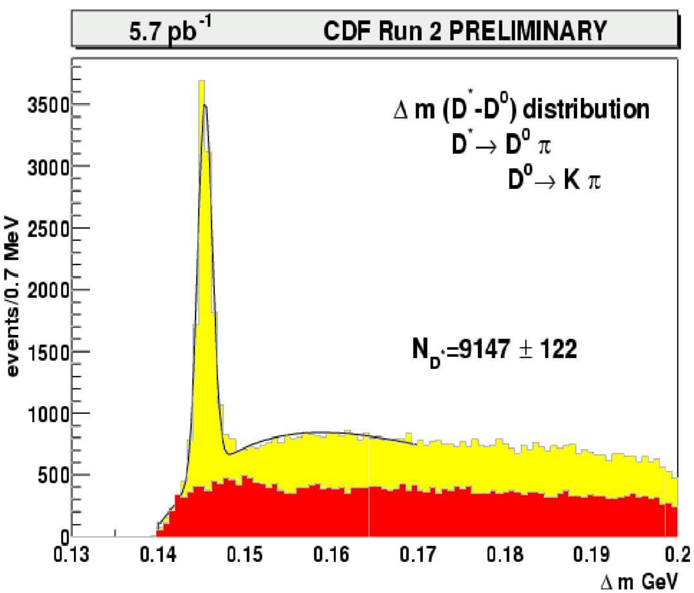


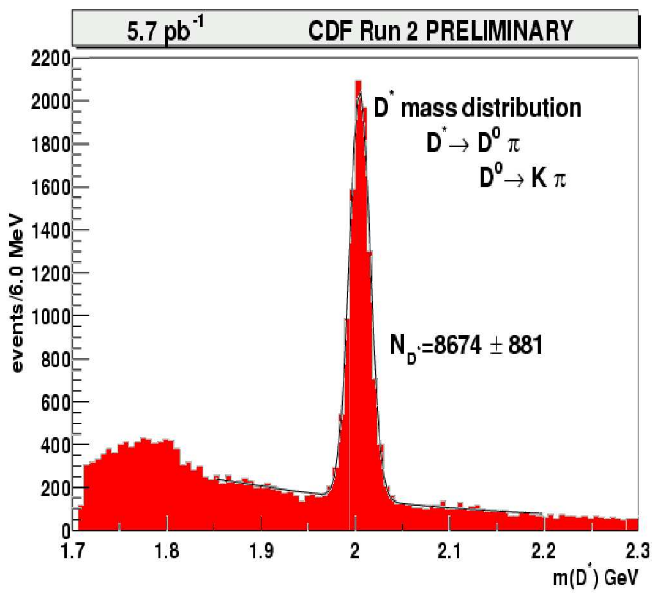


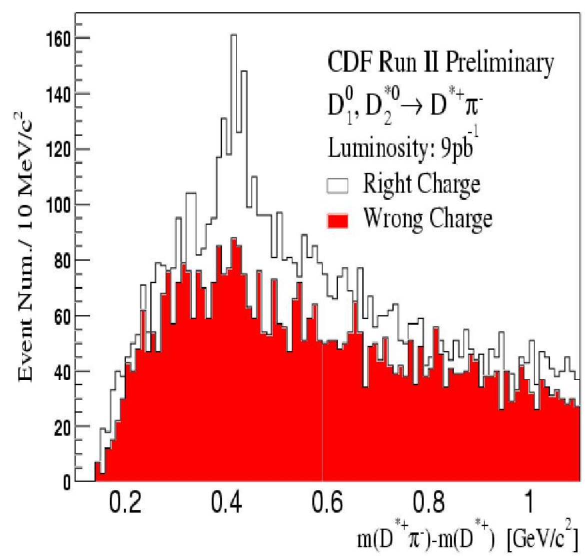
Charm Prospects

- <u>More than one million fully reconstructed charm decays per 100 pb^{-1}</u>
- A full range of charm measurements becomes possible
  - Charm cross sections
  - Relative branching ratios, mass and width measurements
  - Rare and forbidden charm decays
  - $D^0\overline{D}^0$ mixing
  - Direct CP violation

Some are born to discover J/ψ,
some achieve photoproduction of charm,
and some have charm physics thrust upon 'em

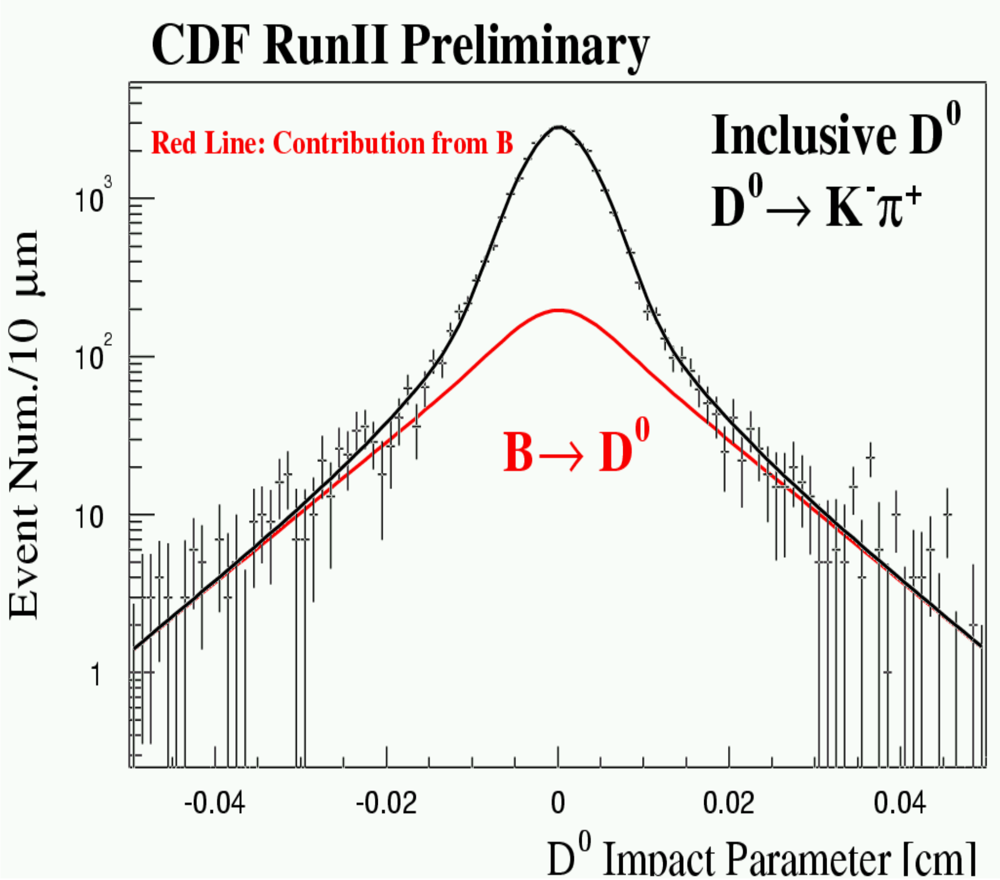






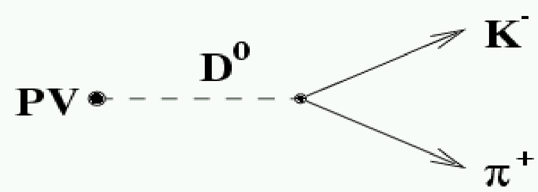
b Fraction in D Samples

Use impact parameter distribution to determine prompt fraction



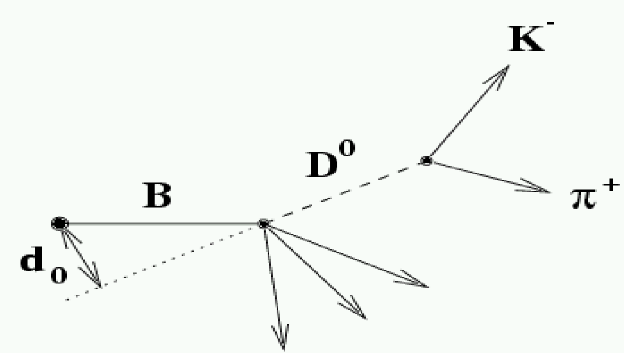
Direct Production

D points back to PV



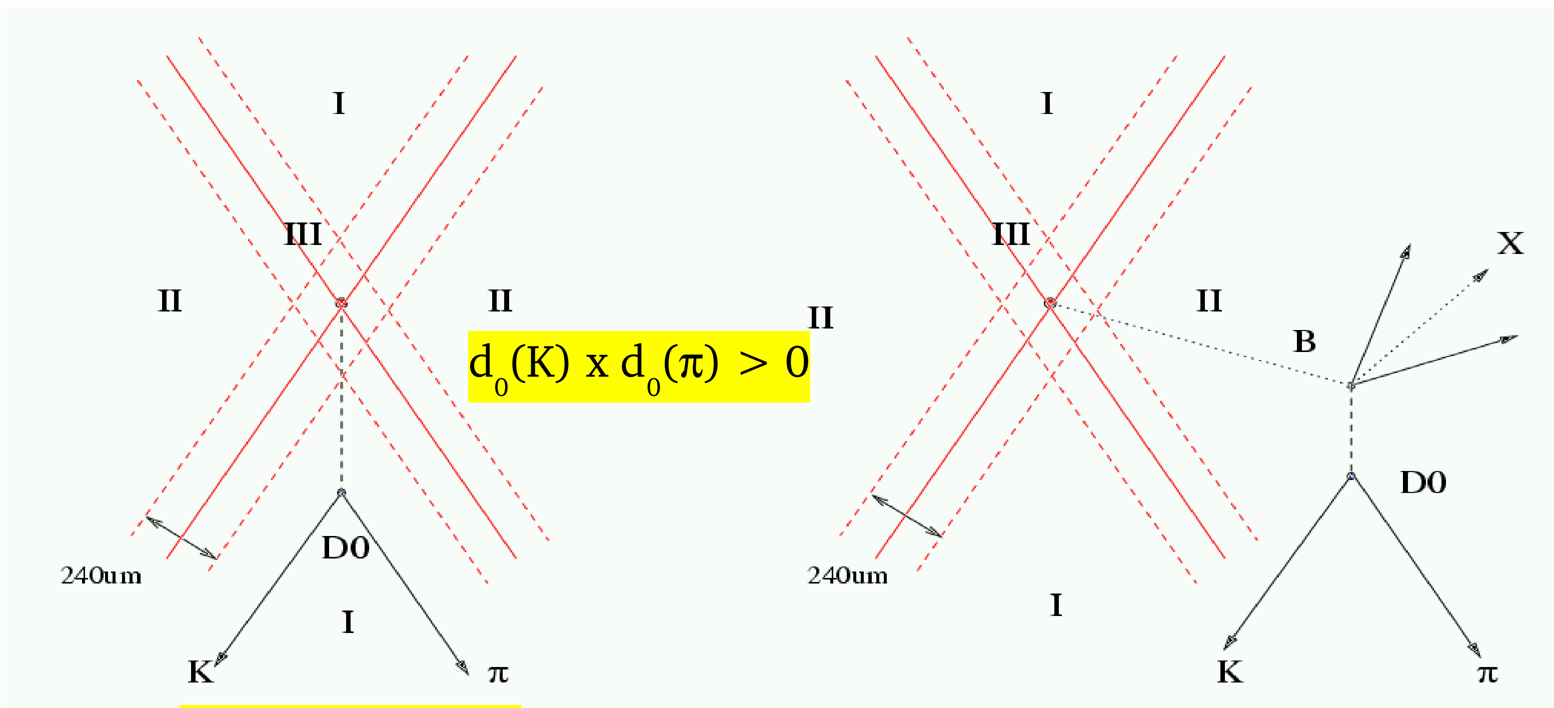
Secondary Production

D has finite impact parameter



Definitions and Trigger Bias

- d_0 Impact parameter = distance of closest approach of the track trajectory to the primary vertex in the rϕ-plane
- L_{xy} Decay length in the rϕ-plane = scalar product of the vector pointing from the primary vertex to the two(N)-track vertex (decay point) and the unit vector pointing along the sum of the transverse momentum vectors of the two (N) tracks



$d_0(K) \times d_0(\pi) < 0$

Direct D^0: only in region I with $L_{xy} > 0$

Secondary: region I or II

Well separated by "forbidden" region III

b Fraction in D Samples cont.

- In about 5 pb^{-1}, we reconstruct for this analysis — B-fraction f_B

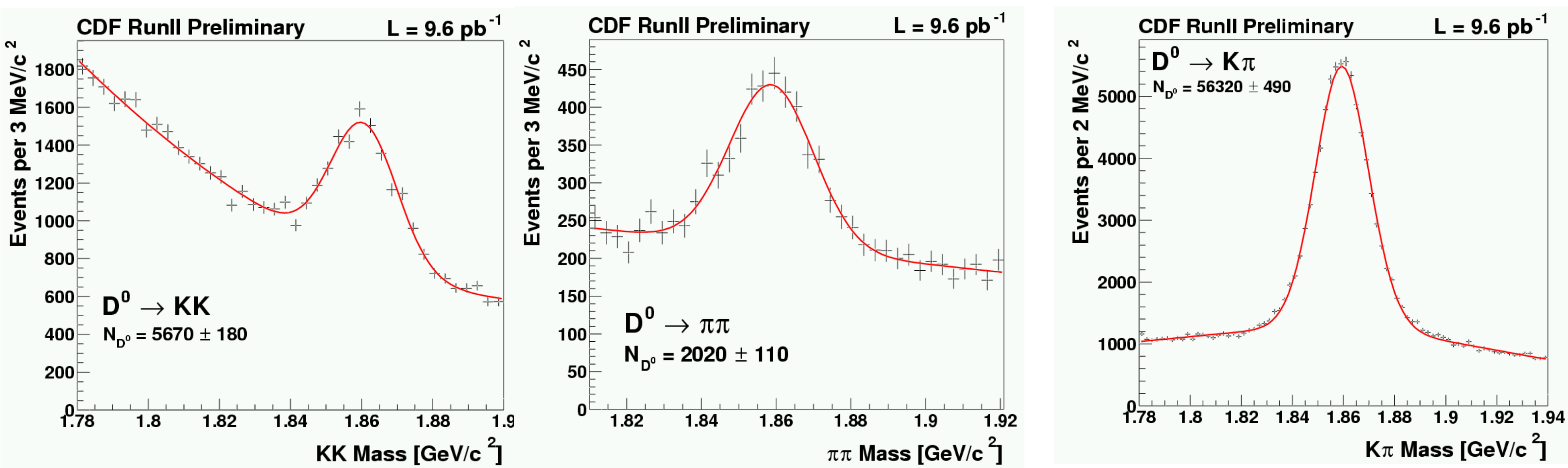
$D^0 \to K^-\pi^+$	33k events	($p_t(D^0) > 5.5$GeV)	15-24 %
$D^{*+} \to D^0\pi_s^+$ with $D^0 \to K^-\pi^+$	6k events	($p_t(D^{*+}) > 6.0$GeV)	9-22 %
$D^+ \to K^-\pi^+\pi^+$	28k events	($p_t(D^+) > 6.0$GeV)	10-18 %
$D_s^+ \to \phi\pi^+$ with $\phi \to K^+K^-$	1.2k events	($p_t(D_s^+) > 6.0$GeV)	29-43 %

- D^0 contains auto-reflection
  - No particle ID $\to$ candidate with Kaon and pion exchanged enters the sample
  - Estimate from D^{*+} with wrong charge combinations: $\simeq$20%. Neglected here, but relevant for cross section and branching ratio measurements
- There is no published charm cross section measurement from the Tevatron
  - Excellent prospects for using this approach as part of a measurement of the direct charm production cross section
  - Of particular interest due to the larger than expected (?) b cross section

BR($D^0 \to K\pi/KK/\pi\pi$) Ratios

- **Large charm yield from Two Track Trigger (TTT) allows competitive measurements already now**
- Example I: relative branching fraction for Cabibbo suppressed D decays
- Ratio of branching ratios → many systematics cancel (normalize to dominant $D^0 \to K\pi$)
- Relative acceptance of the KK and $\pi\pi$ modes is within 10% of $D^0 \to K\pi$

$$\frac{\Gamma\left(D^\circ \to K^+K^-(\pi^\pm\pi^\mp)\right)}{\Gamma\left(D^\circ \to K\pi\right)} = \frac{N_{KK(\pi\pi)}}{N_{K\pi}} \cdot \frac{\epsilon_{K\pi}}{\epsilon_{KK(\pi\pi)}}$$



BR($D^0 \to K\pi/KK/\pi\pi$) Ratios

$$\Gamma(D \to KK) / \Gamma(D \to K\pi) = 11.17 \pm 0.48\ (stat) \pm 0.98\ (syst)\ \%$$

$$\Gamma(D \to \pi\pi) / \Gamma(D \to K\pi) = 3.37 \pm 0.20\ (stat) \pm 0.16\ (syst)\ \%$$

PDG 2002: $10.83 \pm 0.27\ \%$ ($KK/K\pi$)

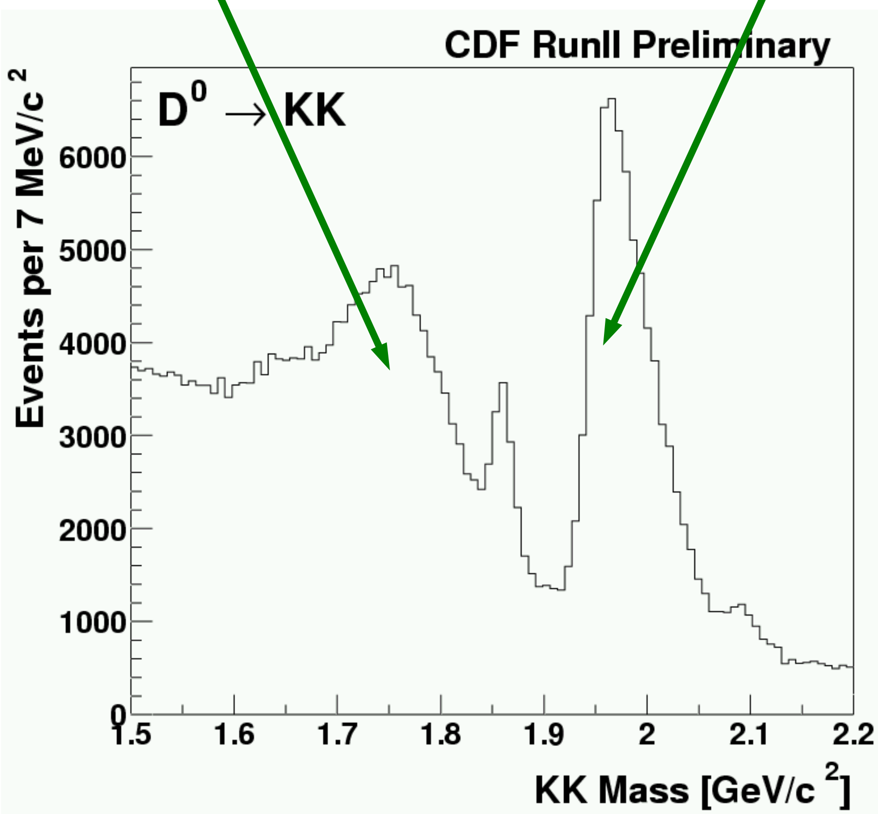
$3.76 \pm 0.17\ \%$ ($\pi\pi/K\pi$)

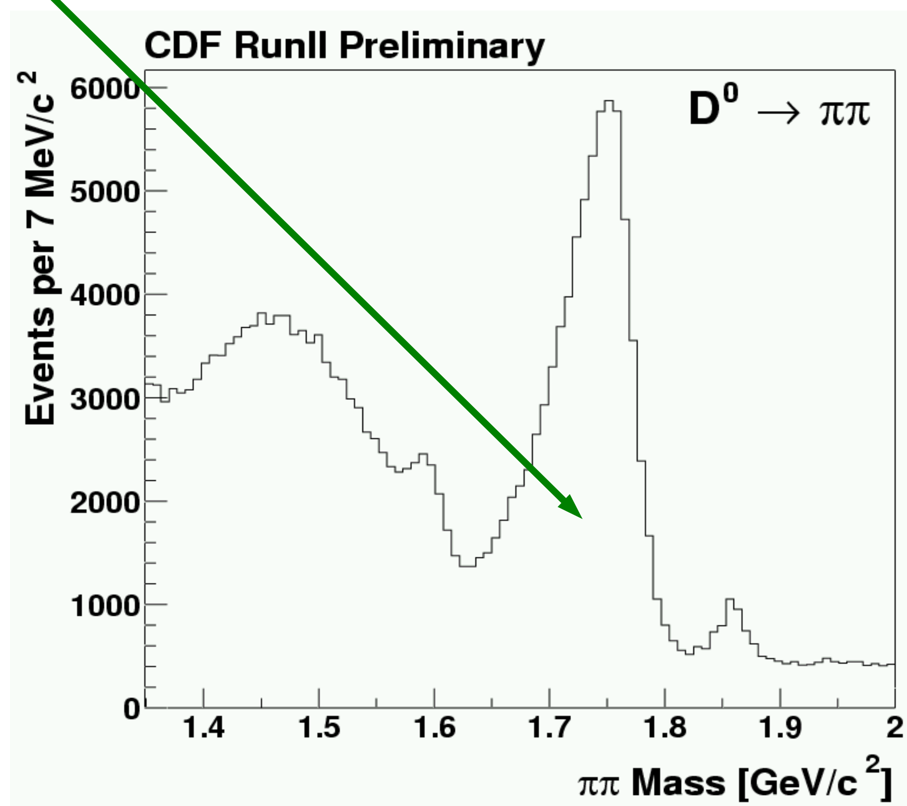
- Main systematic uncertainties
  - Shape of auto-reflection (effect of $K\pi$ swap in $D^0 \to K\pi$ peak)
    - Use $D^{*+} \to D^0\pi^+$, where the charge of the Kaon and Pion are known, to measure from data
  - Background fitting functions
  - Relative reconstruction efficiency

BR($D^0 \to K\pi/KK/\pi\pi$) Ratios

$D^0 \to K\pi\pi^0$ and other partially reconstructed decays

$D^0 \to K\pi$





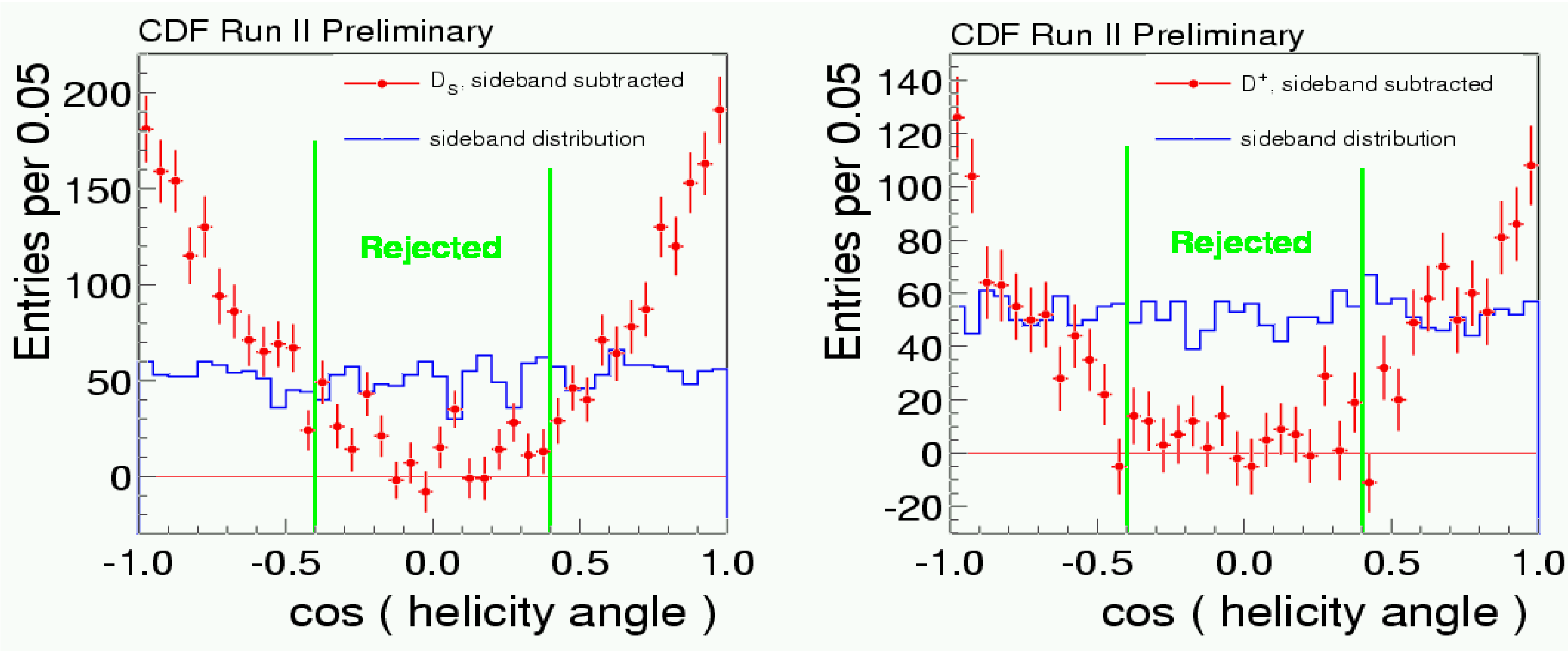
D_s, D^+ Mass Difference

- Example II: **$m(D_s)$-$m(D^+)$, enters the global PDG fit for all charmed meson masses**
- Reconstruct both mesons in the decay channel $\mathbf{D} \rightarrow \phi\ \pi$

$$\begin{array}{l} \mathbf{D}^+ \rightarrow \phi\ \pi \\ \mathbf{D}_s \rightarrow \phi\ \pi \\ \qquad\quad \hookrightarrow \mathbf{KK} \end{array}$$

  - kinematically very similar
  - many systematics cancel
- Spring 2002 data, $\int L\,dt \simeq 11.6\ pb^{-1}$ with reliable COT and Silicon data
- Selection
  - General clean-up cuts: at least 20 COT axial + 20 stereo hits, at least 3 Silicon r-ϕ-hits, $p_t > 400$ MeV for all used tracks, matching in z_0 for all candidate tracks
  - TTT sample → confirm trigger cuts: at least two tracks with $p_t > 2$ GeV, impact parameter $100\ \mu m < |d_0| < 1$ mm
  - Reduce combinatorical background: $L_{xy} > 500\ \mu m$, reasonable vertex fit χ^2
  - Exploit polarization of ϕ coming from D decay: $|\cos\alpha| > 0.4$, where α is the helicity angle (angle between K and D direction in the ϕ rest frame)

D_s, D^+ Mass Difference cont.

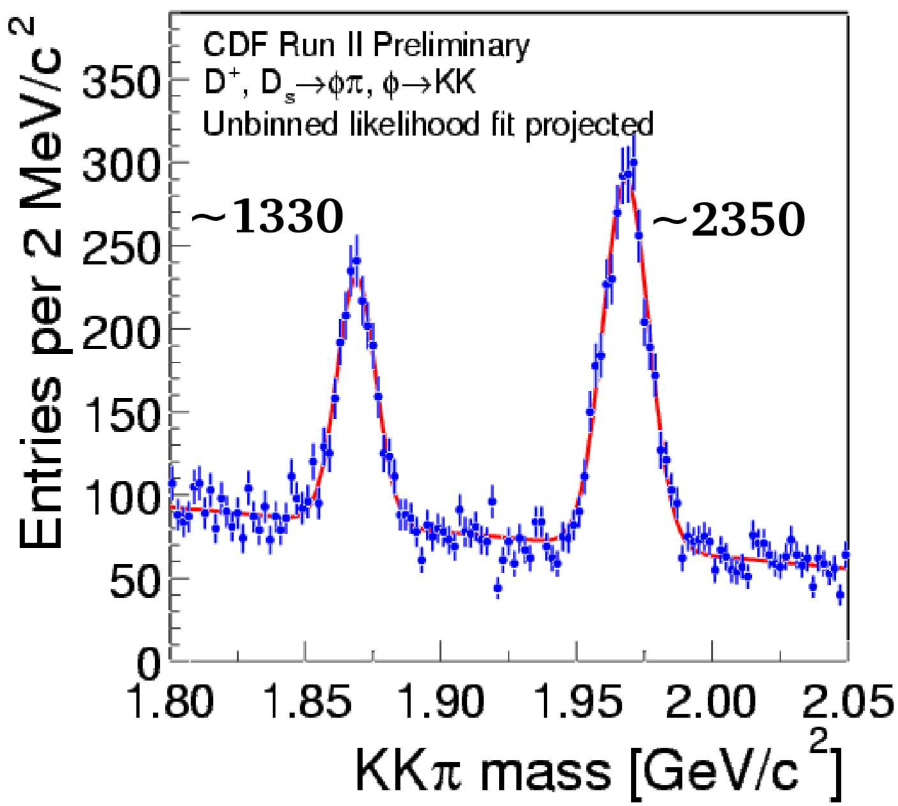


- Main systematic uncertainties

χ^2 cut	0.06 MeV
Helicity angle, L_{xy} cut	0.13 MeV
"false curvature", studied with J/ψ	0.06 MeV
Fitting procedure	0.22 MeV
Total systematic uncertainty	0.27 MeV

D_s, D^+ Mass Difference cont.

- Unbinned maximum likelihood fit on all candidates that pass the selection criteria within $1.80 < m < 2.05$ GeV
- Fitting method tested against toy Monte Carlo to check for *fitting biases* and other problems
- D_s mass comes out right:
  $m(D_s) = 1968.2 \pm 0.3$ MeV (fit)
  $m(D_s) = 1968.6 \pm 0.5$ MeV (PDG)



quality of fit: χ^2/NDF = 136.2/118 (12.0%)

$$m(D_s) - m(D^+) = 99.28 \pm 0.43\ (stat) \pm 0.27\ (syst)\ \text{MeV}$$

(PDG: 99.2 ± 0.5 MeV)

Inclusive B $\rightarrow$ J/ψ + X Lifetime

- "Engineering" measurement, as a precursor to exclusive lifetime measurements
  - Large amounts of J/ψ into dimuons available. Simple and well understood trigger.
- Reconstruct J/ψ $\rightarrow$ Calculate B decay length $\rightarrow$ Fit distribution for lifetime
  - There are a "prompt" (from direct production) and a "lifetime" contribution to J/ψ's
- For fully reconstructed decays: $ct = \frac{L}{\beta\gamma} = L_{xy} \times \frac{m_B}{p_t}$
- Here, the pseudo proper decay length ct of the B hadron (λ_B) is determined using the ct of the J/ψ, involving a correction factor F(p_t(J/ψ)) which is determined from simulations:

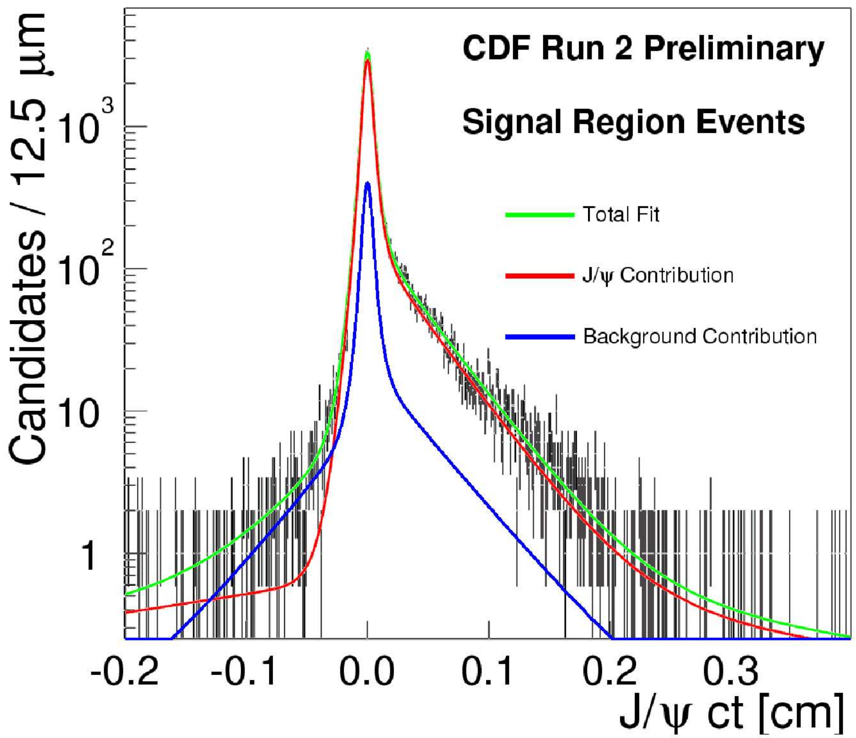
$$F(P_t^{J/\psi}) := \left\langle \frac{ct_{J/\psi}}{ct_b} \right\rangle \qquad \lambda_B = L_{xy} \times \frac{M_{J/\psi}}{p_t^{J/\psi} F(P_t^{J/\psi})}$$

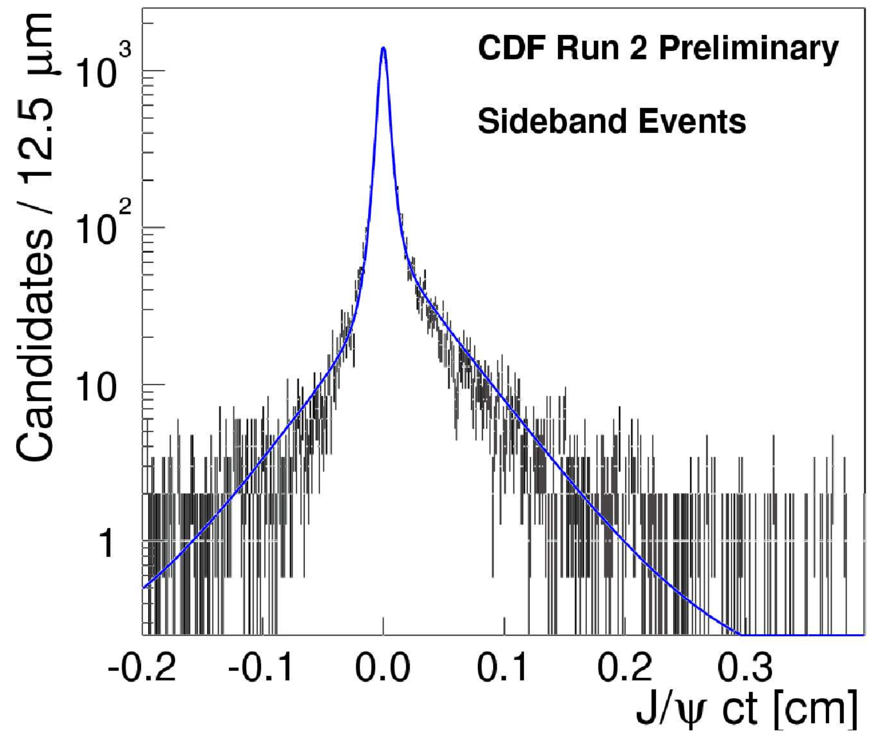
- F is close to 1 and flat for p_t(J/ψ) > 4GeV
  - J/ψ carries most of the momentum of the original b-hadron

Inclusive $B \rightarrow J/\psi + X$ Lifetime

- Data sample:
  - $\sim$28k J/ψ taken in spring 2002 with the dimuon trigger
  - Central (CMU) muons only, $|\eta| < 0.6$, quality cuts on tracks, muons
  - $p_t(J/\psi) > 4$ GeV to minimize systematics
  - At least 3 $r\phi$-Silicon hits
  - Error on decay length projected on transverse plane $\sigma(L_{xy}) < 200\mu m$
- Unbinned maximum likelihood fit
  - Simultaneously fit dimuon mass and B ct
- Major systematics include:
  - F factor (change fragmentation, PDF, m_b, B_s and Λ_b fraction, ...)
  - Alignment (evaluated by random misalignment, and systematic radial shift)
  - Resolution function
  - Background parameterization

Inclusive B $\rightarrow J/\psi$ + X Lifetime





$$c\tau_B = 458 \pm 10 \; (stat) \pm 11 \; (syst) \; \mu m$$

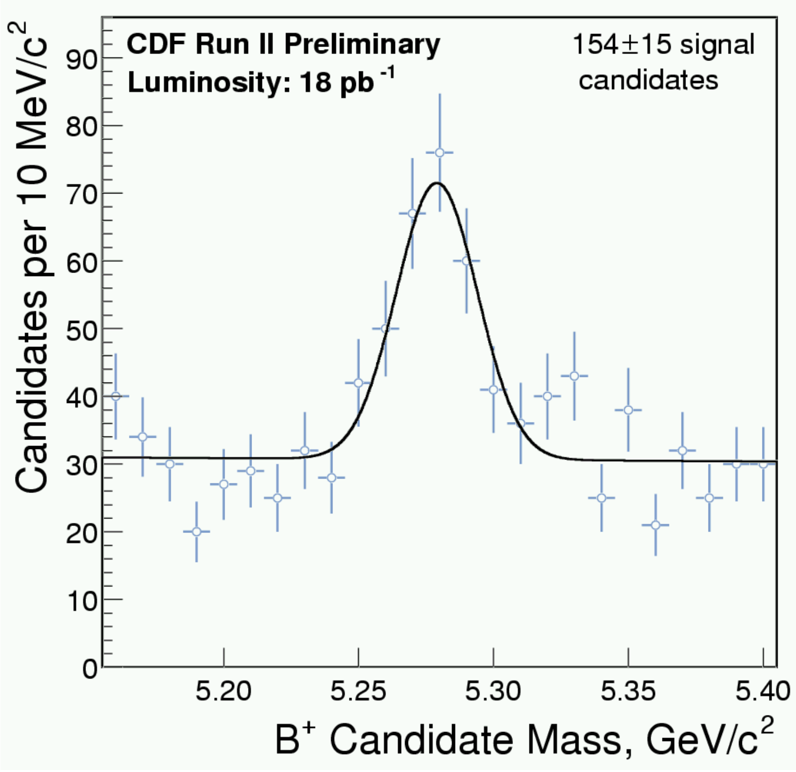
$$\tau_B = 1.526 \pm 0.034 \; (stat) \pm 0.035 \; (syst) \; ps$$

$$c\tau_B \; (PDG) = 469 \pm 4 \; \mu m$$

Exclusive $B \to J/\psi + X$ Lifetimes

- Protoanalysis; not yet competitive due to low statistics
- Show $B^+ \to J/\psi\ K^+$ here
  - Optimized cut values on Monte Carlo for best $S^2 / (S+B)$ at $c\tau > 100\mu m$
  - $p_t(B^+) > 6.5$ GeV and $p_t(K^+) > 2.0$ GeV
  - Vertex fit of the 3 tracks with $P(\chi_{r\phi}^2) > 0.1\%$
  - Standard cuts on muons and tracks
  - $3017 < M(J/\psi) < 3177$ MeV
- Integrated luminosity 18 pb^{-1}
- 154 signal events

$B^+ \to J/\psi\ K^+$



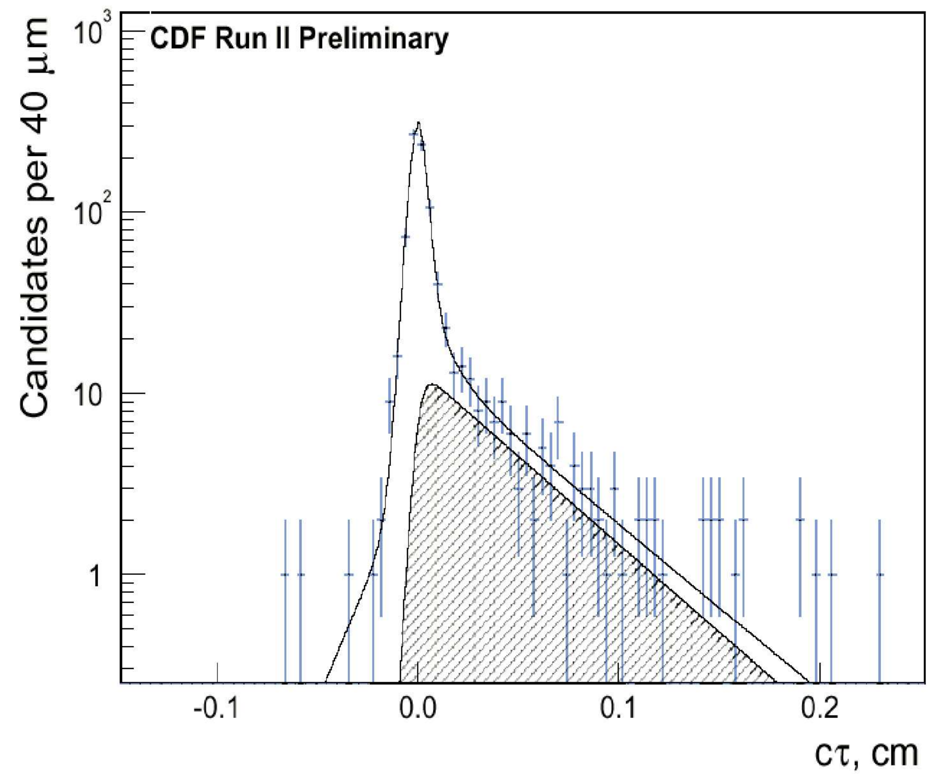
Exclusive $B \to J/\psi + X$ Lifetimes cont.

- Fit model
  - B fraction: exponentially decaying lifetime convoluted with gaussian resolution
  - Non-B (background) contribution: Gaussian at 0 (prompt J/ψ), short-lived positive and negative exponential tails (mismeasured background), long-lived positive exponential tail (sequential B's etc.)
- Fit result

$B^+ \to J/\psi\ K^+$

$c\tau = 446 \pm 43\ (stat) \pm 13\ (syst)\ \mu m$
$\tau_{B+} = 1.49 \pm 0.14\ (stat) \pm 0.04\ (syst)\ ps$

$c\tau_{B+}$ (PDG) $= 502 \pm 5\ \mu m$



- Systematic uncertainties (alignment, fit bias) small compared to present statistical uncertainty
- Present signals for $B^0 \to J/\psi\ K^{*0}$ and $B^0_s \to J/\psi\ \phi$ are statistically too weak

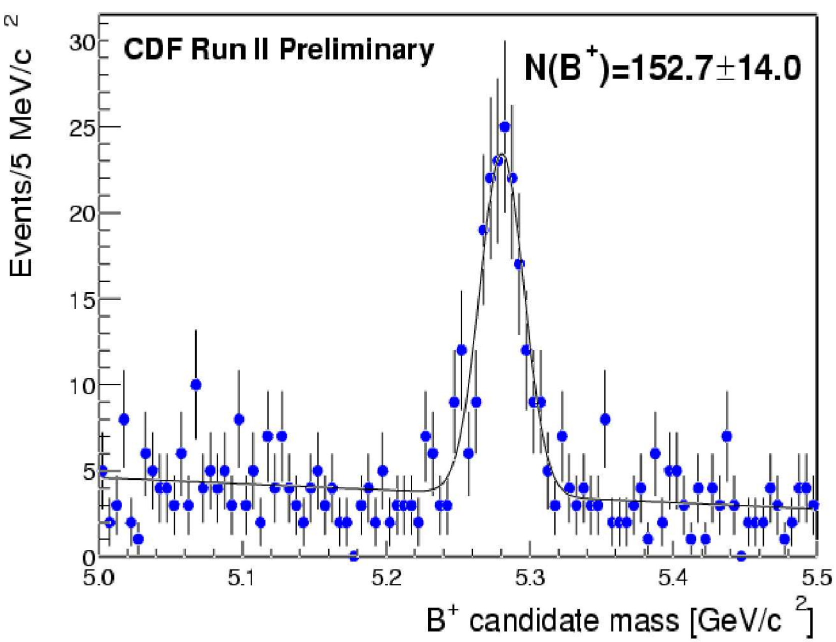
B Hadron Mass Measurements

- Decays reconstructed:

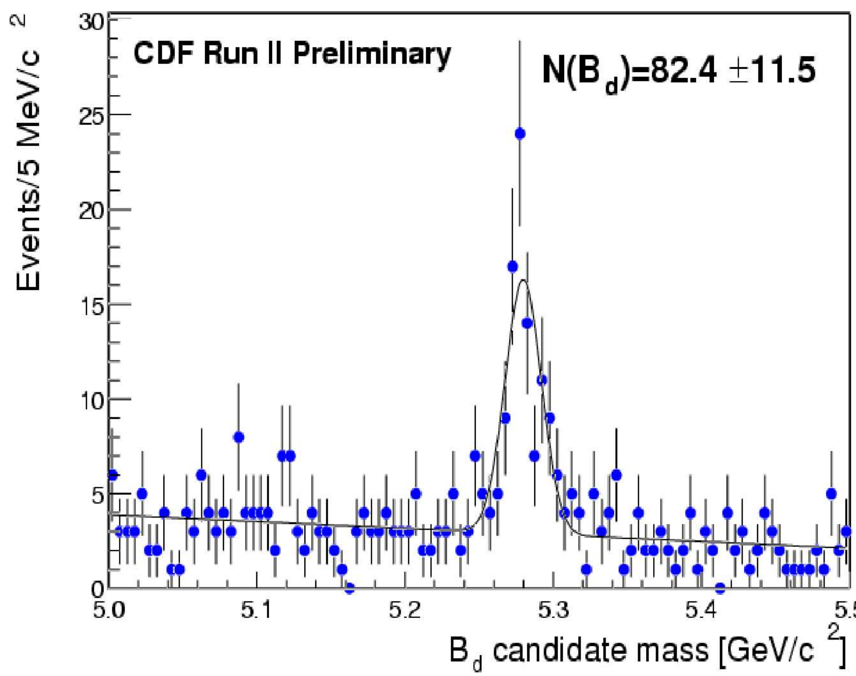
$B^0 \rightarrow J/\psi\ K^{0*}$ with $K^{0*} \rightarrow K^+\pi^-$
$B^+ \rightarrow J/\psi\ K^+$
$B_s \rightarrow J/\psi\ \phi$ with $\phi \rightarrow K^+K^-$
$\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ (for validation)

- Use 18.4 pb^{-1} of integrated luminosity, CMU and CMX muons

$B^+ \rightarrow J/\psi\ K^+$



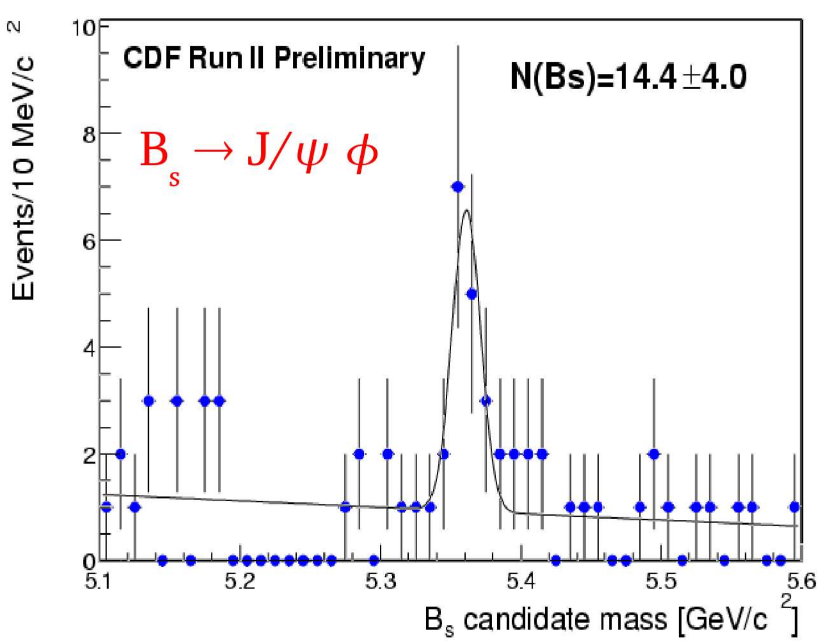
$B^0 \rightarrow J/\psi\ K^{0*}$

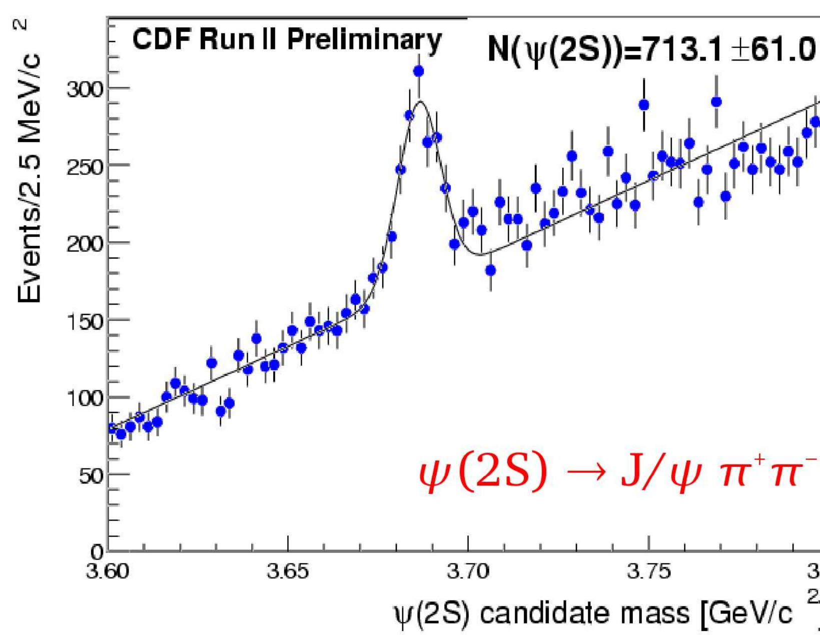


B Hadron Mass Measurements

- Unbinned likelihood fit of masses
  - Gaussian for the signal, linear background
  - Floating width for B^+, B^0, $\psi(2S)$, fixed width for B_s due to small signal
- Present uncertainties ~2-4 times PDG
- Expect to update large part of PDG with more data

$M(B^+) = 5280.6 \pm 1.7\ (stat) \pm 1.1\ (syst)$ MeV
$M(B^0) = 5279.8 \pm 1.9\ (stat) \pm 1.4\ (syst)$ MeV
$M(B_s) = 5360.3 \pm 3.8\ (stat)\ {+2.1}{-2.9}\ (syst)$ MeV
$M(\psi') = 3686.43 \pm 0.54\ (stat)$ MeV





First Fully Hadronic B Signals

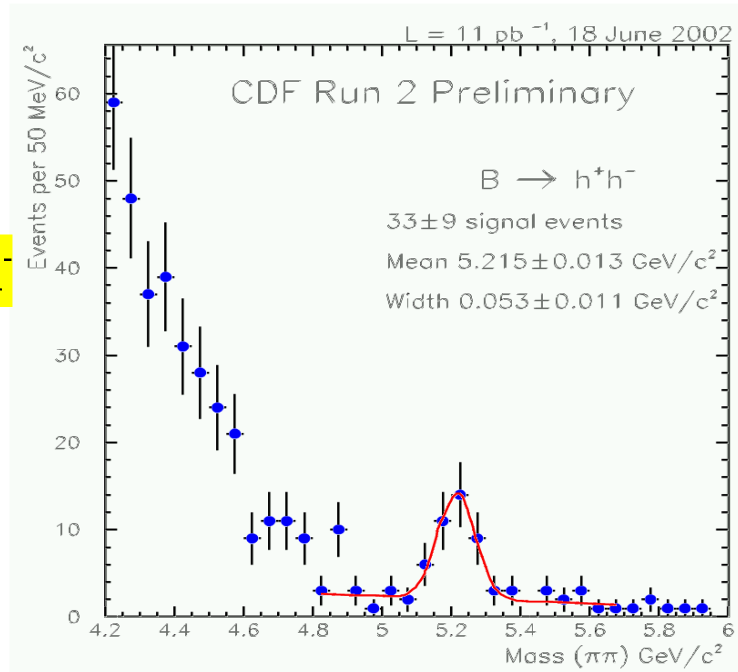
$B^0 \to h^+h^-$

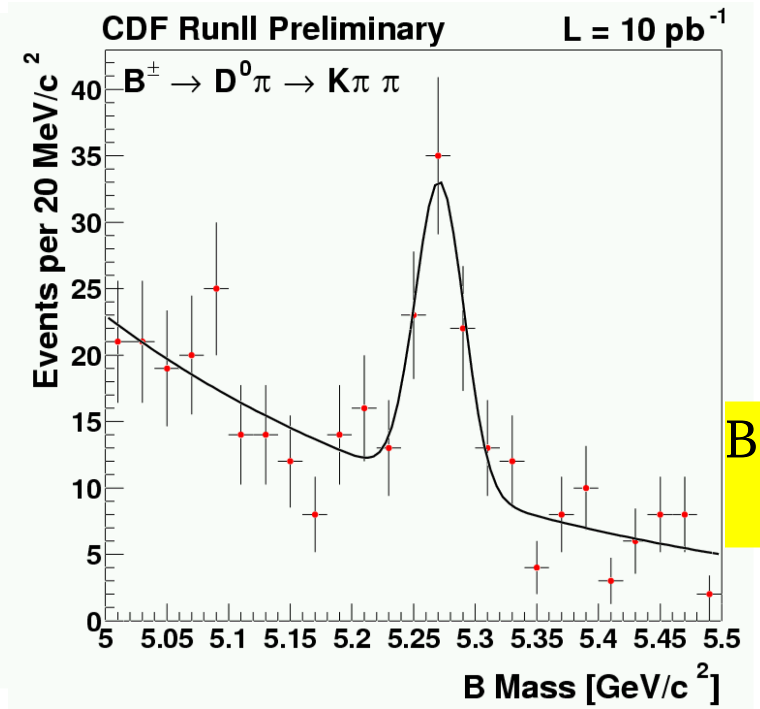
$(B_d \to K\pi$

$B_s \to KK$

$B_d \to \pi\pi$

$B_s \to K\pi)$





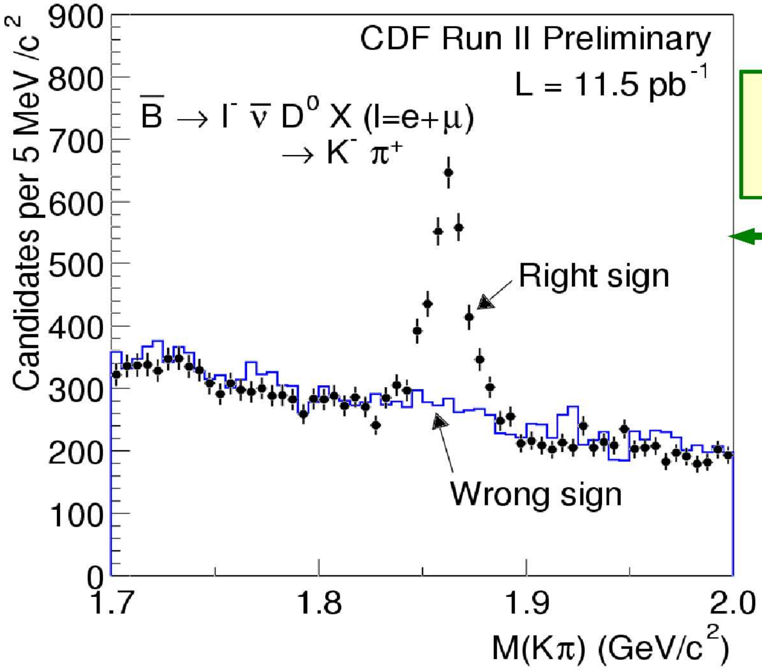
$B^{+-} \to D^0\pi^{+-}$

$\hookrightarrow K\pi$

- Reconstructed from $\int L\,dt \simeq 10\ \text{pb}^{-1}$ of SVT trigger data (status ICHEP 2002)
- Better than expected signal/noise → increased statistical power
- Since then, ~50% improvement of SVT efficiency for hadronic B decays
  - Better SVX coverage
  - Optimized SVT patterns

Semileptonic B Decays

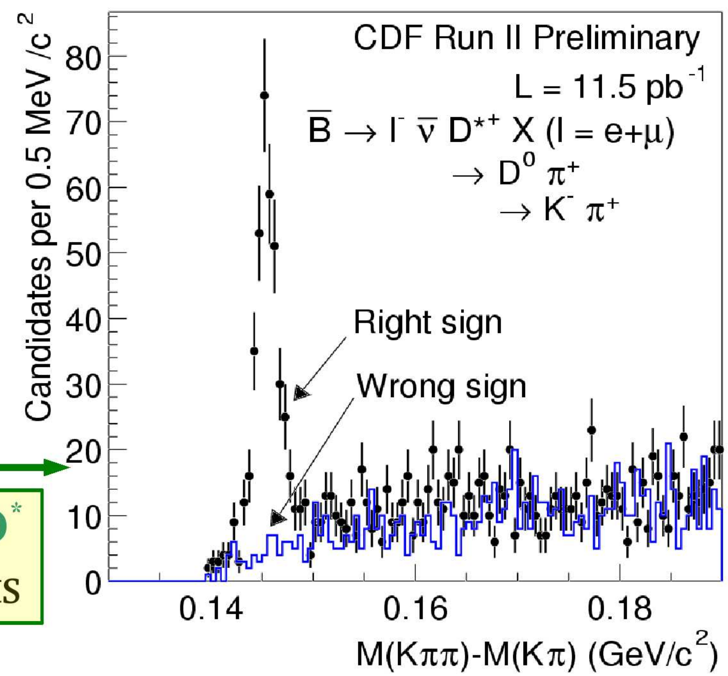
- Two optimized trigger paths: **electron (p_t>4GeV) + displaced track (d_0>120μm)**
  muon (p_t>2GeV) + displaced track (d_0>120μm)



Lepton + D^0
~2000 events

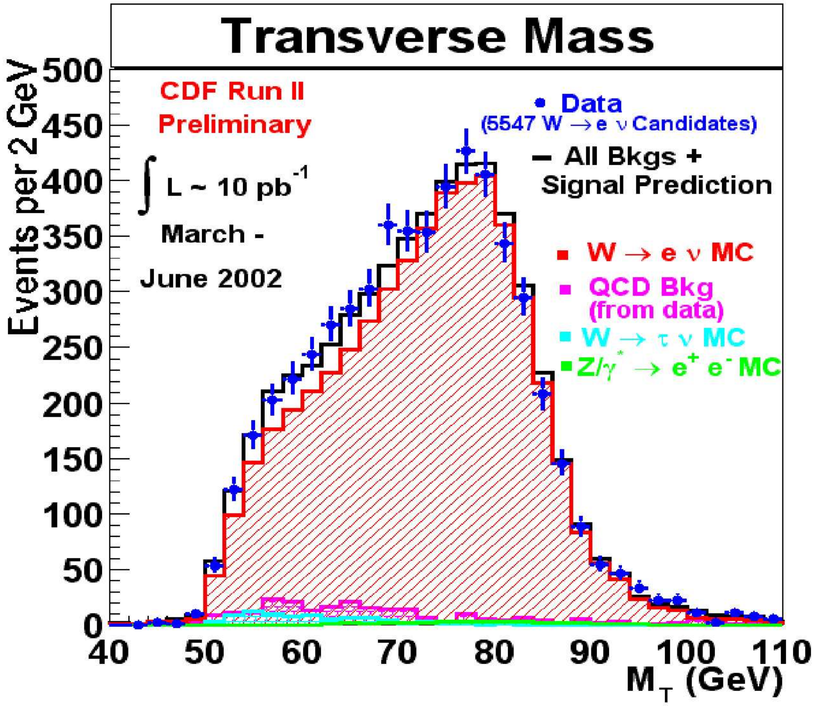
in 11.5 pb^{-1}

Lepton + D^*
~350 events



- Best sample to measure effective dilution of tagging algorithm for B mixing
- "Right" sign correlation between lepton charge and the charge of the Kaon from D meson is a tag for $B \to l\nu D$ decays
- Huge sample (yield 3x Run I) for measurements of lifetimes, CKM (V_{cb}), and study of b/c baryons

$W \rightarrow e\nu$, $W \rightarrow \mu\nu$ Cross Section



$|\eta_e| < 1.0$

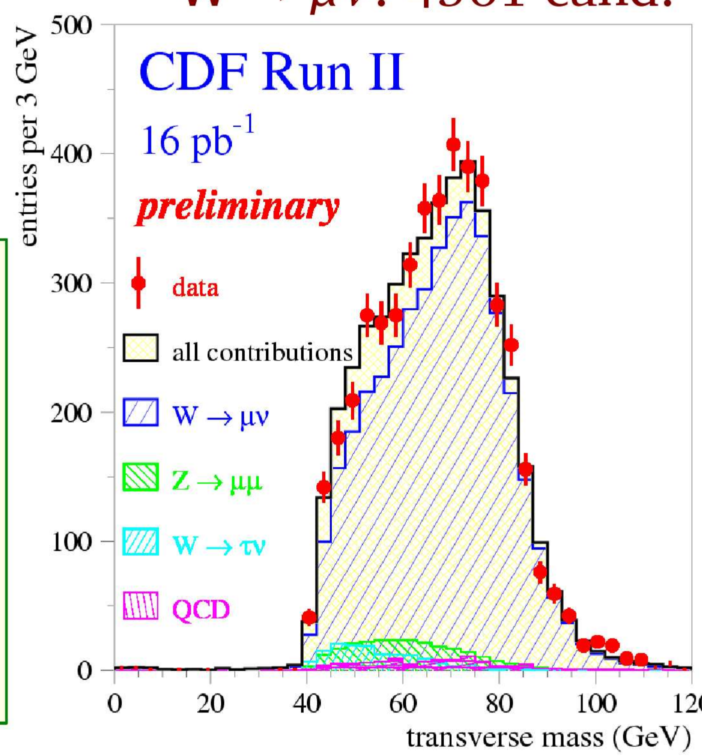
$E_t^e > 25$ GeV

$\not{E}_t > 25$ GeV

$E_t^{ISO} < 4$ GeV

$\Rightarrow$ 5547 candidate events

$W \rightarrow \mu\nu$: 4561 cand.



0.13 now

$\sigma \cdot BR(W \rightarrow e\nu)$ =

2.60 ± 0.03 *(stat)* ± 0.13 *(syst)* ± 0.26 *(lum)* nb

$\sigma \cdot BR(W \rightarrow \mu\nu)$ =

2.70 ± 0.04 *(stat)* ± 0.19 *(syst)* ± 0.27 *(lum)* nb

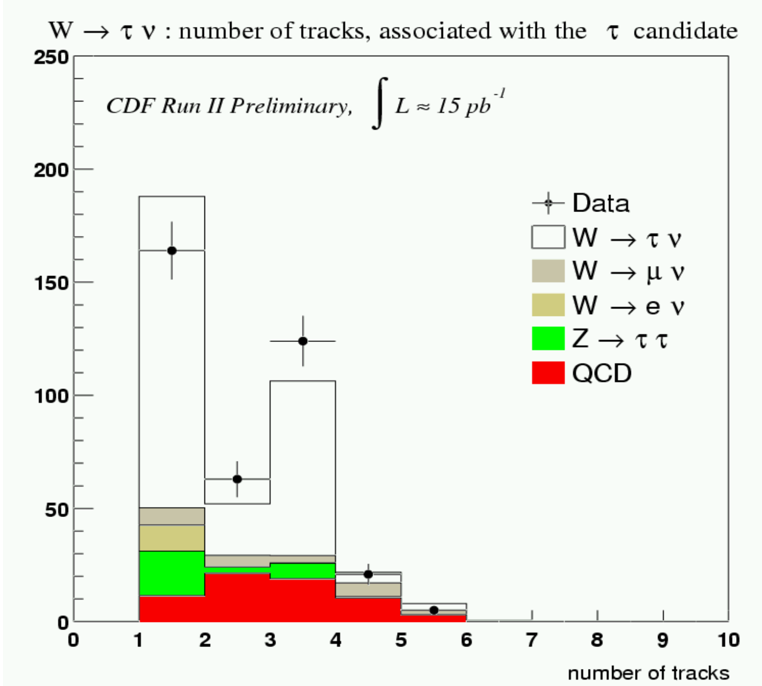
CDF Run I: $\sigma \cdot BR(W \rightarrow e\nu)$ =

2.49 ± 0.12 nb **($\sqrt{s}$ = 1.8 TeV)**

NNLO Theory (Stirling):

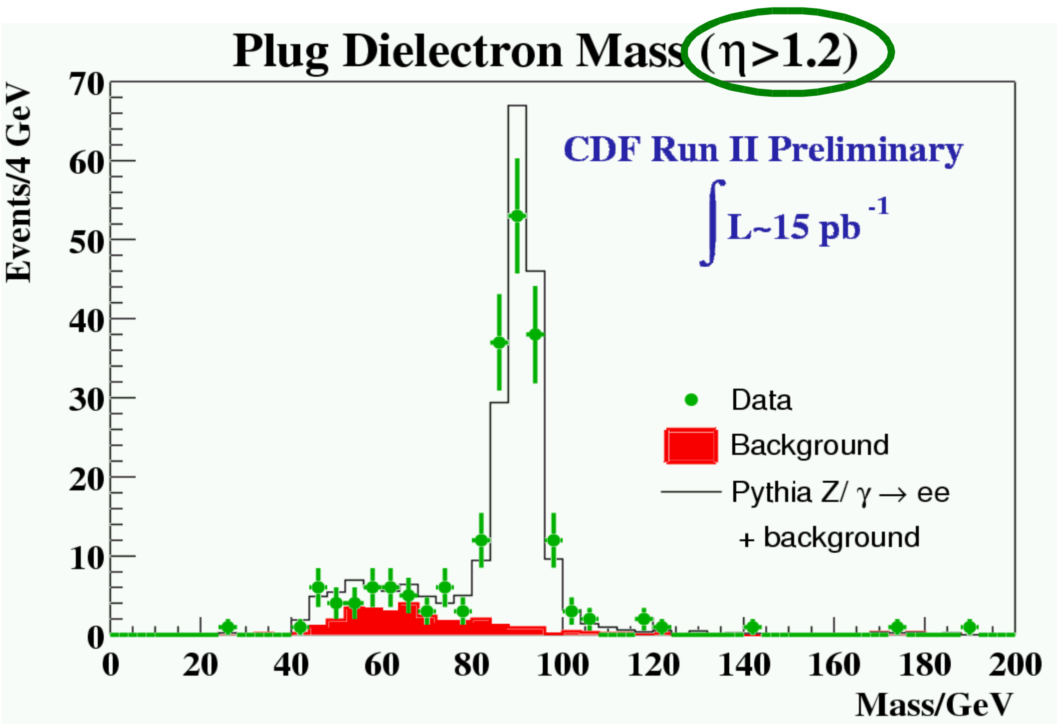
2.50 nb ($\sqrt{s}$ = 1.8 TeV), 2.73 nb ($\sqrt{s}$ = 1.96 TeV)

$W \to \tau\nu$, $Z \to ee$



Observe $W \to \tau\nu$ decay

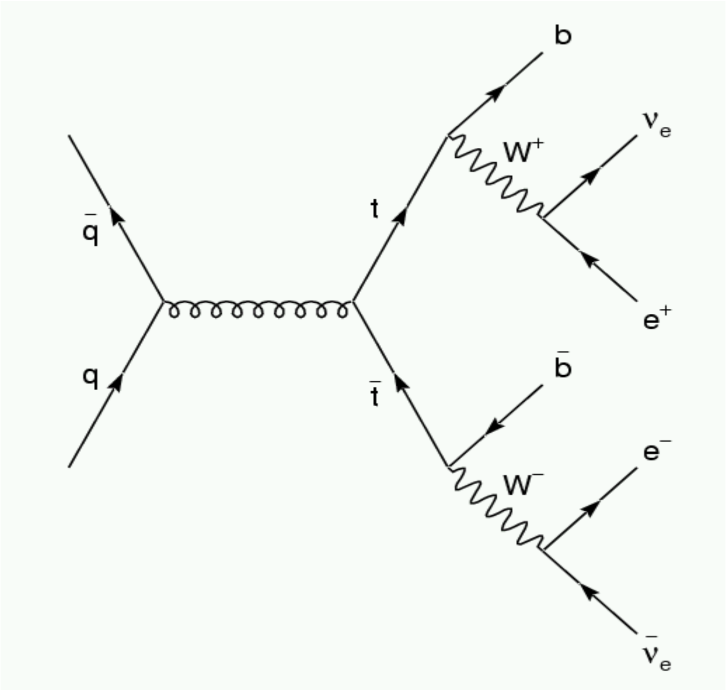
τ channel important for many searches (Higgs)



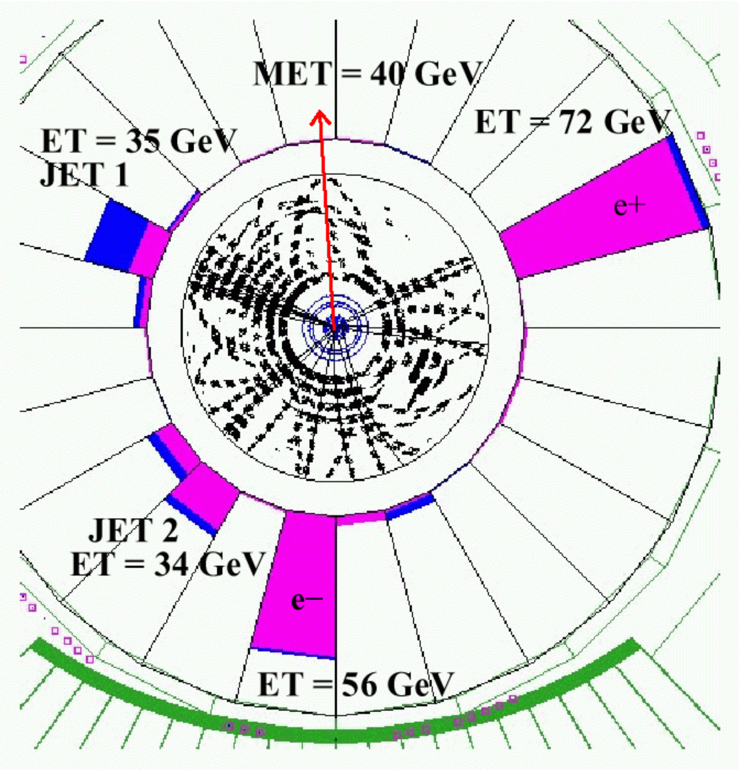
Increased acceptance for leptons out to $|\eta|<2$ (Silicon)

Sample	Run I	Run IIa
$W \to \tau\nu$	77k	2300k
$Z \to ll$	10k	202k

Towards Top



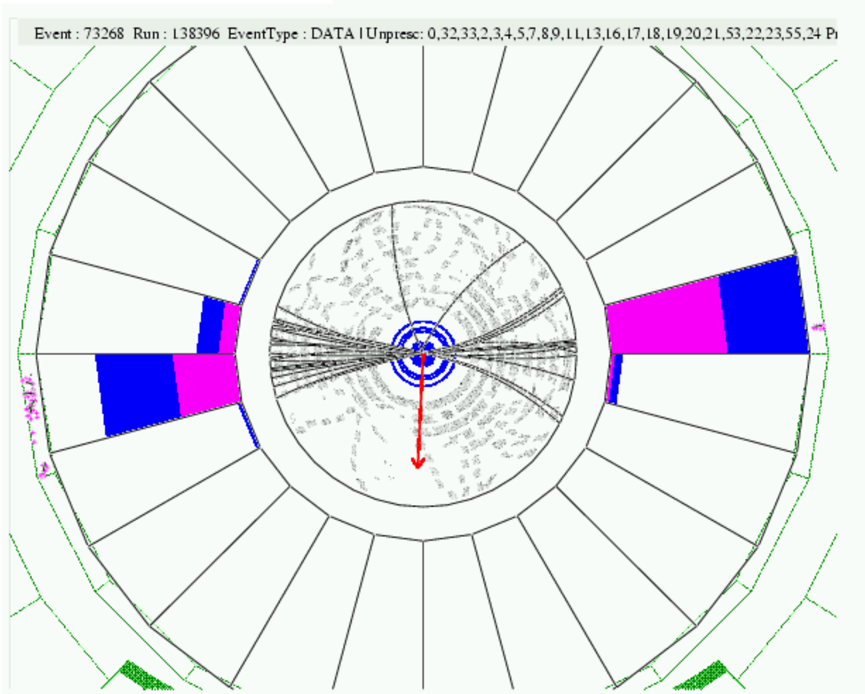
Top candidate event

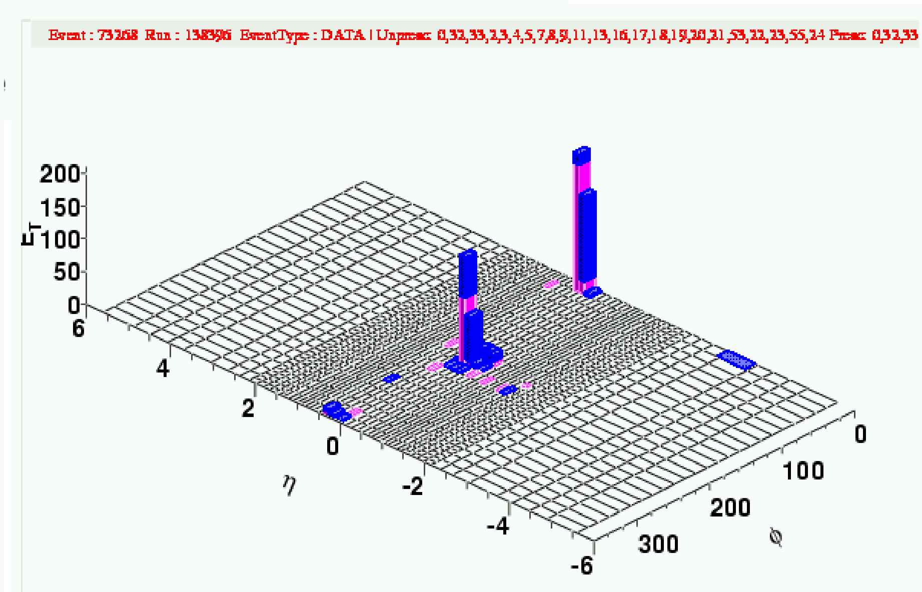


- Expect preliminary measurements of $t\bar{t}$ cross section by Spring 2003

High E_t Jets

- Jet E_{T1} = 403.3 GeV, η_1 = 0.037 (uncorrected)
- Jet E_{T2} = 322.0 GeV, η_2 = −0.364 (uncorrected)





- Remember Run I high E_t jet cross section anomaly (in the end resolved by increased gluon density at large x) – one of CDF's flagship analyses
- Measure jets with E_t out to 550 GeV
- Forward jets (proton structure at high *x*), running of α_s, productions properties of W/Z bosons, Drell-Yan lepton pairs, direct photon production, ...

"CHAMPS"

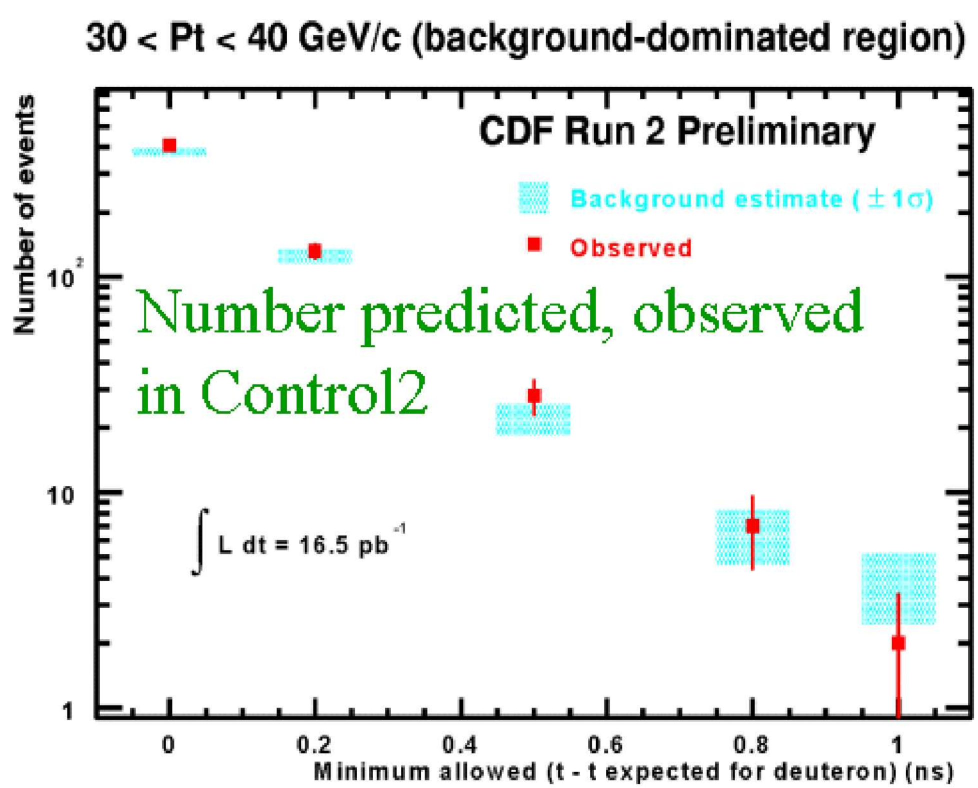
- CHAMPS: <u>long-lived, massive charged particles, isolated</u>
- Models with CHAMPS: e.g. heavy quarks, SUSY (e.g. Sleptons)
- Previous CDF search used dE/dx (little discriminating power at high p_t)
- New **Time-of-Flight** detector can be highly efficient to detect slow-moving particles!

Signal: $\mathbf{p_T > 40}$ **GeV**

Control1: $20 < p_T < 30$ GeV

Control2: $30 < p_T < 40$ GeV

$$ToF_{Diff} = ToF_{measured} - ToF_{expected}(\text{Deuteron})$$



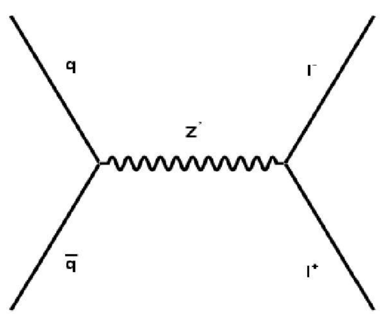
Expected background:

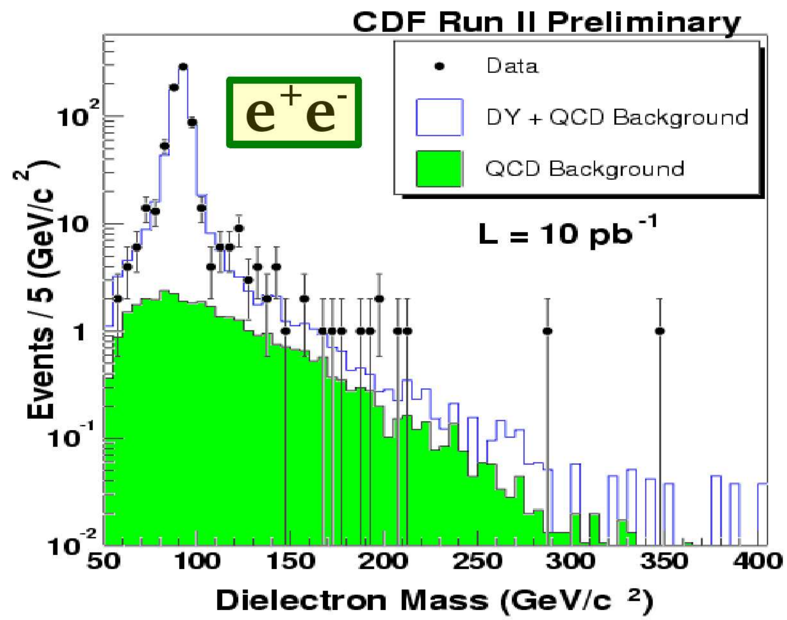
$$N_{Sig}^{TOF_{Diff}>m} = \frac{N_{Sig}^{TOF_{Diff}>-0.2}}{N_{Control}^{TOF_{Diff}>-0.2}} \times N_{Control}^{TOF_{Diff}>m}$$

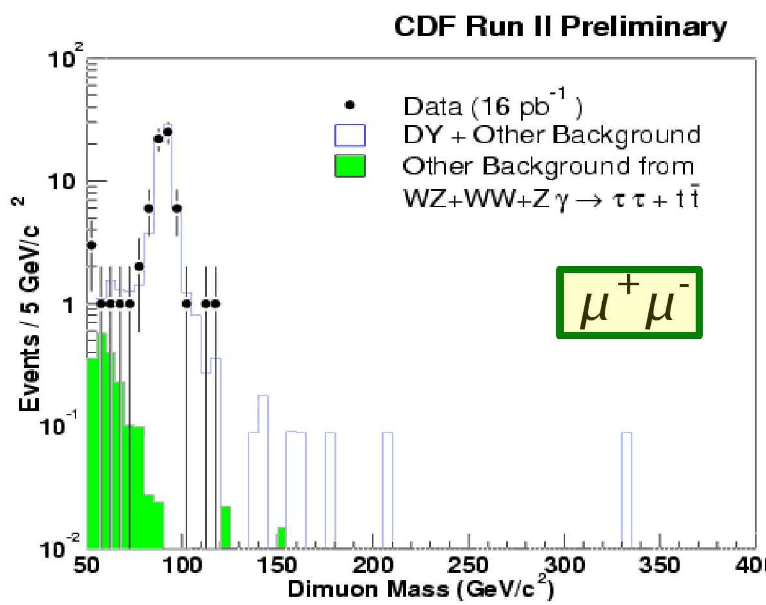
2.2 ± 0.8 bck. exp. ($TOF_{diff} > 1.0$ ns)

Searches in Drell-Yan Dileptons

- Searches using Drell-Yan production
  - Heavy neutral gauge boson Z'
  - Randall-Sundrum graviton resonances
- In e^+e^- with $\int L\,dt \simeq 10\ pb^{-1}$ luminosity:
  $M_{Z'} > 460$ GeV
- Expect **$M_{Z'} > 1000$ GeV** for $Z' \rightarrow ll$ (SM couplings) in Run IIa







Summary

- **More than six years after the end of Run I, CDF can show the first physics results from Run II**
  - Masses, lifetimes, branching ratios etc. from b- and c-mesons
  - W, Z cross sections
  - A few others that I haven't shown
- After a slow startup, accelerator is beginning to show its potential
  - Recent performance improvements are encouraging - many problems have been identified and are being addressed, like bad transfer efficiencies, long range beam-beam effects in the Tevatron, large transverse emittance in the Accumulator, ...
- Early results also made possible by detector upgrades that allow previously impossible measurements
  - Prime example: hadronic B trigger. Tevatron+CDF provide an excellent charm factory.
- Although the CDF detector is almost fully commissioned, there remain areas of concern: e.g. damaging the Silicon detectors
  - Previous accidents had severely reduced our ability to efficiently take data
- Stay tuned for exciting results in the near future